GRADING & BASE MANUAL

Developed by
Pavement Engineering Section
Grading & Base Unit

FOREWORD

Grading and Base Construction utilizes large quantities of materials. The control of the quality and placement of these materials involves the application of various test procedures and inspection techniques to insure the materials and the manner in which they are placed comply with the specification requirements.

This manual is intended as a tool to help the Inspector measure the quality of the materials and evaluate the work as construction progresses.

Application of the procedures described in the manual will assure uniformity of methods throughout the state and will insure the materials are placed as prescribed in the specifications.

Grading and Base Engineer
Minnesota Department of Transportation

PREFACE

The final control of the quality of materials and their use must be accomplished through on-the-job inspection by the supervising engineer and his inspectors. The ultimate responsibility rests with the field personnel to see that materials used meet the requirements of the specifications, that prescribed procedures are followed when so specified, and that required end results are obtained.

This manual has been prepared to assist in accomplishing the control functions of sampling, testing and inspection on Grading and Base Construction projects. Emphasis has been placed on procedures for field use and the application of the test results in controlling aggregate production and construction methods. A section on the basic concepts and classification of soil materials is included.

SUMMARY OF CONTENTS

INDEX NO. SUBJECT

5-692.000 GENERAL

5-692.000 DUTIES OF THE INSPECTOR

A. General

1. The primary duty of the Inspector is to inspect. This means to critically observe the materials and procedures to insure that the construction is performed in close conformity with the plans, specifications and special provisions. To accomplish this, he must have a thorough knowledge of the specifications and special provisions that apply to his particular portion of the work.

2. He must verify that the materials used meet requirements and that they are incorporated into the work in accordance with the specifications. Materials control is accomplished by sampling and testing procedures. The sampling and testing procedures outlined in this manual are part of the contract for the project and are used as the basis for accepting or rejecting the materials. Because these procedures are a part of the contract, it is important that there should be no deviations from the prescribed procedures.

3. In general, the tests should be considered to be a tool used to assist the Inspector in evaluating the work. If the test results do not agree with what he sees, the Inspector should investigate immediately to determine why. For example, if the embankment area is hard and firm, but the density test indicates that the density fails to meet requirements, he should immediately inspect the test area and re-test. He should review the test procedures, check calculations, check file samples used for comparison and check for broken or faulty equipment. On the other hand, if the roadbed appears to be soft and yielding but the test indicates that moisture and density requirements have been met, he should also check every phase of the work. It must be borne in mind that a quality final product, not the individual test, is the goal. The inspector should concentrate his efforts on visual inspection and strive to keep testing at a minimum level.

B. Preliminary Work

1. Before any work is started, each inspector and tester should check every phase of the work to which he will be assigned. This should include a study of the plans to determine construction details, sources of materials, planned limits of select soils, depth and disposition of topsoil, compaction and moisture requirements, disposal of unsuitable soils, preparation of sub-foundation, culverts, gravel pits and details of swamp excavation, fill and overload. He should prepare a memorandum for the project engineer including any questions about any of these items and questions relating to pertinent specifications or special provisions.

   Those items relating to the Contractor can be then resolved in the Pre-Construction conference and those relating to special provisions or specifications can be referred to the District Office or Central Office for interpretation. Much of the difficulty that arises during the work can be avoided by resolving controversial items before the work is started.

2. A field inspection of the project should be made. Cut faces on grading projects should be examined to provide information on soil types that will be uncovered during the work. Auger borings should be made to supplement this information and to determine the approximate limits of each major soil type. Copies of the detailed soil boring notes made during the preliminary soil survey and copies of preliminary soils tests should be obtained from the District Soils Engineer and used to assist in the field review. Samples of the major soils types should be taken, moisture-density tests made and file samples retained for reference during construction.

3. On base construction projects, the grade should be examined for weak areas. The location of these areas should be recorded and auger borings should be made. If the borings indicate the need for a possible subgrade correction, the District Soils Engineer should be consulted for his recommendations.

5-692.001 GRADING CONSTRUCTION

Step 1 Preparation of Embankment Areas

The embankment area should be prepared in accordance with 2105.3B. of the specifications. Topsoil should be reserved in accordance with Specification 2105.3D.

Determine culvert locations. See that treatments, if required, are staked to provide the required tapers. See 5-692.401 for culvert inspection and installation.

Step 2 Excavation Areas

The Contractor should maintain excavation areas in a well drained condition at all times. Excavation areas that impound water are in violation of the specifications.

Soils being excavated for use in embankment construction should be examined carefully. The best materials should be selected for use in the upper portion of the embankments. The poorer soils should be placed in the lower portion of the embankments. Unsuitable soils should be disposed of in accordance with Specification 2105.3D.

Soil selection is one of the most important functions of the grading inspector. The grade is the foundation upon which the final structure will rest and will ultimately support the loads imposed on it after the road is opened to traffic. The materials selected to serve as a foundation structure should be the best available.

For all grading projects, a soil survey has been made prior to design to determine what kinds of soil will be uncovered at or near grade line. Samples of these soils have been tested and their engineering properties evaluated. This information has been applied to the design of the project to make use of the best soils where they will do the most good and place the poorest soils where they will have the least detrimental effect. It is the inspectors responsibility to see that the intent of the plans is carried out.

There are several tools available to the inspector to assist him in soil selection. They are Soil Classification and Identification by texture, identification by soils groups and the use of the Group Index.

1. Soil Classification and Identification by texture is covered in detail in 5-692.600.

2. Identification by soils group is covered in detail in 5-692.600.

3. Group Index is covered in detail in section 5-692.600.

Items 2 and 3 are determined from tests made in the laboratory. However, those values have been determined for samples tested in connection with the soils survey. Copies of these test results should be obtained from the District Soils Engineer and used for reference.

Every effort should be made to select soils in such manner that a roadbed composed of uniform soils is obtained, particularly in the upper one meter (3 feet) of the grade.

The Contractor's foreman should be advised as to where you want the soils placed in the embankment. It is easier to obtain cooperation before the soils are hauled to the embankment area. In ordering selection or mixing of soils, the inspector should be aware of the restrictions imposed in 2105.3D.

Step 3 Excavation Below Grade

Subcuts should be excavated to the planned dimensions. Prepare the bottom of the subcut in accordance with Specification 2105.3E.

In cases where the bottom of the subcut will not support the equipment and the backfill is placed in one layer in accordance with the provisions of 2105.3E(1), it is desirable to end dump; then mix and spread thick layers with a dozer. Do not permit the use of compactive equipment that will distort the bottom of the subcut.

If the open subcut reveals conditions such as water or badly mixed soils and no special treatment for these conditions is provided, it may be desirable to provide either granular or more uniform soil backfill. The District Soils Engineer should be consulted and his recommendations followed.

If unsuitable soils are encountered below the planned subcut, additional excavation may be required. Contact the Project Engineer and the District Soils Engineer and follow their recommendations.

Step 4 Spreading and Compacting

Embankment Materials
(See specification 2105.3E and 2105.3F).

Every effort should be made to obtain sufficient mixing to prevent large pockets of different classes of soils from being placed in localized areas.

The work should be observed to insure that compaction equipment operates uniformly over the entire embankment areas.

Step 5 Control Testing for Embankment Construction

All granular items should be tested by the Contractor and certified on Form 24346 (Certification of Aggregates and Granular Materials) prior to delivery and placement on the project. The Contractor's rate of testing should be sufficient to guarantee that uniform acceptable material is being delivered to the project. The Project Engineer is responsible for acceptance testing in accordance with the Schedule of Materials Control.

The Moisture-Density Test, Field Density Test and Field Moisture Test are used to determine compliance with the specifications. These tests are tools to be used by the Inspector to verify his visual observations. As far as possible, the Inspector should strive to keep testing at a minimum and do more visual inspection.

Whenever a moisture-density determination is made, a file sample should be retained in a moist condition and placed in a glass jar with a screw-on cap. The curve number, textural classification, maximum density and optimum moisture should be recorded on a label affixed to the jar. (See Section on Soil Classification and Identification in 5-692.600).

The field moisture test (5-692.245) is used to determine compliance with the specification for moisture at the time of compaction. The sample for this test should be obtained while the material is being compacted. The sample should represent the work being done. This requires close observation of the work.

The field density test (5-692.246) is used to determine compliance with the compaction specification. This test should be coordinated with close visual inspection.

The Quality compaction specification implies close visual inspection of the entire operation by an experienced inspector. Continuing observation of uniform compaction effort and moisture control are crucial to the successful use of this specification.

Much unnecessary testing can be avoided by good visual inspection. Observation of the work to insure uniform compaction effort and moisture control will reduce the number of tests required. Close inspection of a grade meeting requirements plus picking with a sharp tool will give an inspector a good idea of what the passing grade should be like. Other areas can be checked in this manner and only a sufficient number of tests should be made to verify the inspector's judgment. Areas failing or yielding under construction traffic should be investigated and corrected.

Note: The use of **nuclear density testing devises** for density verification and acceptance will **not** be allowed under any of the density or compaction requirements listed in Specifications 2105, 2211, or 2221.

Step 6 Measurement

Measurement and document all pay items according to the provisions in Specification 1901 and Section 5-591.410 of the Contract Administration Manual.

5-692.002 BASE CONSTRUCTION

Step 1 Subgrade Preparation (Specification 2112)

Take a sufficient number of field density tests to insure compliance with the specified density in the upper 150 mm (6”) of the grade. Areas failing or yielding under construction traffic should be investigated and corrected.

Check the grade for compliance with tolerance requirements. It is not necessary to check all points. Spot check short sections of 100-150 meters (300-500 feet). If the Contractor is checking the grade, it is sufficient to observe and record his measurements. An occasional slight deviation is acceptable.

Step 2 Aggregate Gradation

Samples for the gradation test should be taken at a time when the material has been mixed and is ready for compaction. Sample and test in accordance with 5-694.215M or .215E and 5-694.700.

Specifications 3138 & 3149 provide crushing requirements for Classes 5 and 6 and for Aggregate Bedding and Stabilizing Aggregate. Determine the percent of crushing in accordance with 5-692.203 or 5-692.204.

Shale requirements are also specified in 3138. The rate of testing will be determined by the Engineer based on past record from that source or preliminary tests.

Step 3 Substitution of Savaged Material (Class 7)

The substitution of salvaged materials as Class 7(__) may be subject to added testing requirements and/or restrictions as specified in 3138. Example – Maximum allowed bitumen content of Class 7(B) is 3.0%, which requires bituminous extraction testing.

Step 4 Moisture Control

The sample for moisture control should be taken from the windrow at the time of compaction.

Step 5 Spreading and Compacting

The spreading process acts as another mixing step to make the aggregate more uniform.

Step 6 Compaction Control

Base aggregate shall be constructed in layers not more than 75 mm (3") in compacted thickness, except that each layer compacted with approved types of special compacting equipment may be increased to a maximum of 150 mm (6"). Vibratory rollers will be allowed for use on a performance basis in accordance with Specification 1805. Density and moisture testing will be conducted as per the project's Schedule of Materials Control.

Materials that contain a high percentage of crushed particles tend to resist consolidation by normal compaction methods. The inspector should carefully monitor moisture and layer thickness to assure adequate compaction with minimal damage to the particle size and shape.

Salvaged materials used as Class 7(__) may not be as durable or sound as virgin aggregates. Most of these materials are susceptible to degradation by excessive compactive efforts.

Note: The use of **nuclear density testing devises** for density verification and acceptance will **not** be allowed under any of the density or compaction requirements listed in Specifications 2105, 2211, or 2221.

Step 7 Workmanship and Quality

It is not required to check tolerance on each class of material. Only the final layer of base is required to meet tolerance requirements. Intermediate layers shall be constructed in reasonably close conformity with the cross-section shown in the plans.

Step 8 Measurement

Measure and document all pay items according to the provisions in specification 1901 and section 5-591.410 of the Contract Administration Manual.

5-692.100 Sampling, Random Sampling and Splitting

This Section summarizes the following:

- General Sampling Requirements
- Rate of sampling
- Contractor Quality Control (QC)
- Agency Verification Testing (VT)
- Random Sampling
- Non-Random Sampling
- Splitting
- Sampling for Independent Assurance Sample
- Special Sampling for Individual Tests
- Sample Identification
- Documentation

5-692.101 General Sampling Requirements

- Ensure that the sample represents the material being placed.
- Use a square head shovel to obtain samples.
- Do not mix underlying material with the sample.
- Use a separation fabric (such as a geotextile or a polyethylene sheet) when sampling layers less than four inches thick. Separation fabric may also be used for thicker layers.
  - Note: place separation fabric at the bottom of the layer to be sampled. After material is placed, but before it is compacted, collect the material placed upon the separation fabric, as the test sample.
- Label and store in a sample bag, plastic pail or other suitable container.
- Deliver samples as soon as possible.

.102 Rate of Sampling (Schedule of Materials Control)

The Schedule of Materials Control outlines the **minimum** required sampling and testing rates. Always use the Schedule included in the contract, as requirements and rates may change.

Take additional samples when there is an unusual variation of material properties. Compute an average, to determine compliance, using these additional tests results along with your original testing results.

.103 Sampling at the Source (Contractor)

Obtain samples from a stockpile. Stockpile should be uniformly blended.

.106 Sampling for Embankment Construction

Obtain the samples after spreading, but before compaction. Sample for gradation in areas most likely to fail and sample for qualities according to the random sampling procedures in section 5-692.125.

.107 Sampling from the Road for Base, Surface and Shoulder Aggregates

Obtain a sample after spreading, but before compaction. Sample according to the random sampling procedures in section 5-692.125.

.110 Contractor Quality Control (QC) Testing, Sampling (Stockpile & Roadway) and Certification

- The Contractor's testing agent must be MnDOT certified in aggregate production.
- Follow all applicable sampling and splitting procedures in this section, and the testing procedures in section 5-692.200.
- Attach all production test reports to form G&B-104 (TP 24346), Certification of Aggregates, either prior to delivery or with the first load of material.
- The Contractor's Authorized Representative must sign the certification.
- Provide test reports to the Engineer within 24 hours.

.111 Contractor Control Charts and Tables

If required by the Contract, produce and maintain control charts and tables (see example Table 5-692.111-A and Figure 5-692.111-1).

A control chart consists of plotting the following information, for each individual sieve, controlled by a given specification, on one graph:

- Percent passing verses sample number and
- Moving average using the previous four tests.

A control table summarizes the data plotted in the control chart in a tabular format.

Include the following information on each control chart and table:
- class of material,
- specification limits and
- project number.

Additionally, include the following information on the control table:
- date,
- moving average,
- test number and
- tester initials.

Round results as follows:

Sieve Size	Rounding Method
Larger than #200	1% (nearest percent)
Less than #200	0.1% (nearest tenth of a percent)

Table 5-692.111-A

Sample Data Table Class 5, No. 40 sieve gradation, spec minimum = 10, Spec Maximum = 35.

Test #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Result	32	36	39	35	24	27	29	30	28	31	26	25	22	20	19	25	26	25	27	28
Moving Avg				36	34	31	29	28	28	30	29	28	26	23	22	22	22	24	26	26
Date	5/1	5/1	5/1	5/1	5/1	5/3	5/3	5/3	5/4	5/5	5/5	5/6	5/7	5/8	5/9	5/9	5/9	5/9	5/9	5/9
Tester	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ	IJ

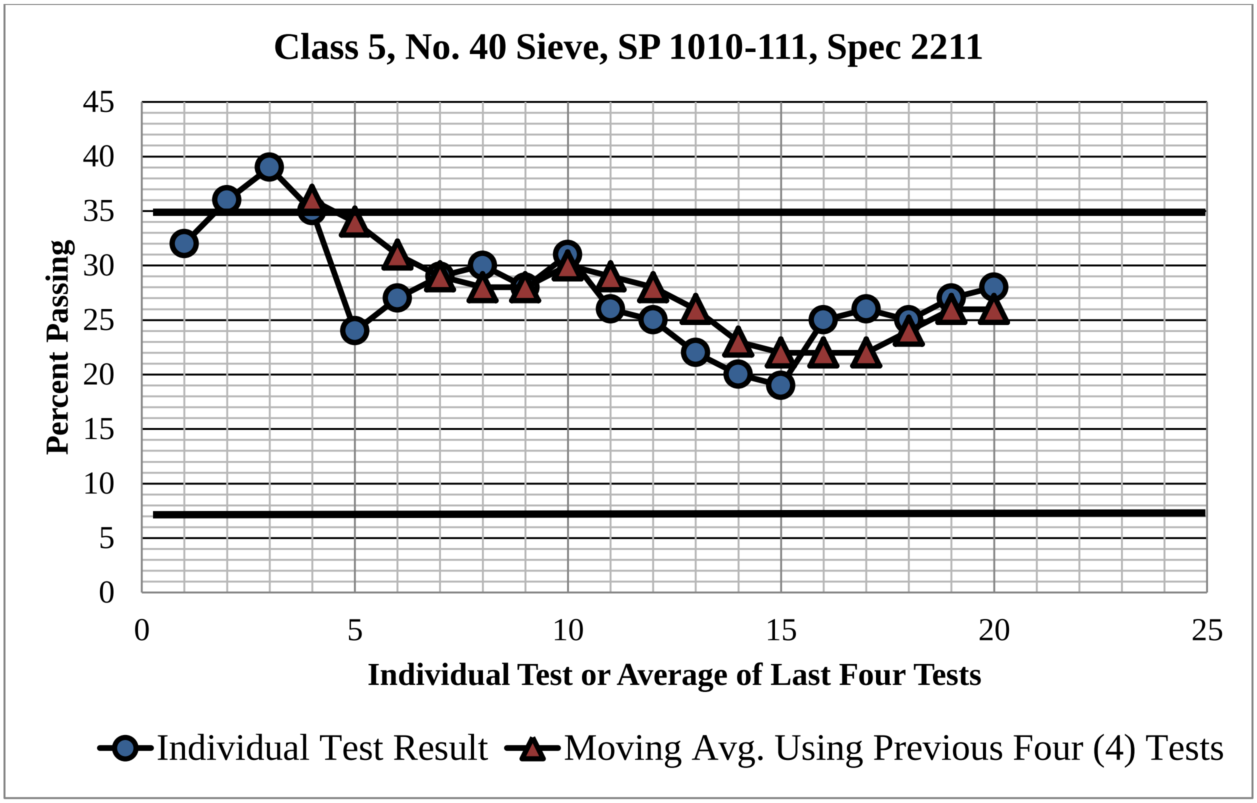


Figure 5-692.111-1

.120 Agency Verification Testing (VT): Roadway Materials Sampling and Testing

- The Agency's testing agent must be MnDOT certified in aggregate production.
- Sample material per the rate in the Schedule of Materials Control.
- Sample material, according to what method applies per the specifications, either randomly per section 5-692.125, or non-randomly per section 5-692.130.
- Submit all gradation test results to the Contractor within 24 hours, and all quality test results within seven (7) days.

.125 Random Sampling Procedures

This section covers verification sampling and testing by the Random Sampling Method.

A General

1. A Lot contains material from one pay item.
2. Lot sizes can be adjusted to allow for year-end cutoffs, lengthy interruption of work, etc.
3. Sampling should not be done until the Contractor has notified project personnel that they have completed all road blending.
4. Lot sizes and the sampling rate are determined by the Schedule of Materials Control.
5. Each Lot should be divided into two or four sublots, see the Schedule of Materials Control.
6. Divide Lots into equal quantities. Divide sublots into equal quantities.
7. Average the results from each Lot to determine compliance.
8. Sample selection and location is the responsibility of the Engineer.
9. Locate sample sites using GPS, pacing or a measuring device. They do not need to be surveyed.

B Lot Determination

1. Determine number of Lots by dividing total quantity by maximum Lot size.

Round to the next higher number.
Example: Quantity = 12,000 yards
Maximum Lot size equals 5,000 yards
Number of Lots = 12,000/5,000 = 2.4, round up to 3 Lots

2. Determine Lot Size by Dividing the quantity by the number of Lots

Example: 12,000 yards/3 Lots = 4,000 yards per Lot.

3. Determine Sublot size by dividing the Lot size by two or four, whatever is applicable (Note in most cases divide by four, see Schedule of Materials Control).
4. Example 4,000 Yards/4 = 1,000 yards per sublot.

C Testing

1. Test according to the procedures in 5-692.200's.
2. Report results on forms from the Grading and Base website, or on standard laboratory forms.
3. Notify the Contractor, as soon as possible, when a Lot fails to meet requirements.
4. The Contractor is required to run new tests, when corrective work is performed.
5. Sample and test, using new randomly selected locations, after receiving new passing results from the Contractor for corrective work.
6. Any monetary price adjustments will be determined by the most recent tests and applied to the entire Lot.

D Random Samples

This section describes random sample selection by using random numbers to determine sample location.

i. Random Number Selection

Document how random numbers are obtained. You may use the method in this section or another random number generator.

1. Chose a random starting number by randomly opening a book. Use the resulting page number as the starting number.
2. Enter Table 5-692.125-A at the top left and count vertically by columns or horizontally by rows to the designated number chosen in step 1 above. Proceed to the next column or row, when the end of the given column or row is reached. This is the first random number to use. Use the next consecutive number, in either the column or the row, depending on which procedure is used, as the second number and so on. Again, when reaching the end of the column or row, proceed to the start of the next column or row, respectively.
3. Continue use the consecutive numbers for the rest of the project regardless of material classification or type of test that is being sampled.

Example: Open a book to page 38. Starting at the top left (top of the first column on the left) count down to the 38th number. The first random number is .84. From this point use consecutive numbers, i.e., the 39th (.18) the 40th (.79), etc. for the rest of the project regardless of material classification or type of test for that is being sampled.

Table 5-692.125-A
Random Number Generator Table

.53 .74 .23 .99 .67 .63 .38 .06 .86 .54 .35 .30 .58 .21 .46 .63 .43 .36 .82 .69 .98 .25 .37 .55 .26	.61 .32 .28 .69 .84 .99 .00 .65 .26 .94 .06 .72 .17 .10 .94 .65 .51 .18 .37 .88 .01 .91 .82 .81 .46	.94 .62 .67 .86 .24 .02 .72 .90 .23 .07 .25 .21 .31 .75 .96 .61 .38 .44 .12 .45 .74 .71 .12 .94 .97	.98 .33 .74 .19 .95 .79 .62 .67 .80 .60 .49 .28 .24 .00 .49 .32 .92 .85 .88 .65 .24 .02 .71 .37 .07	.47 .53 .53 .38 .09 .75 .91 .12 .81 .19 .55 .65 .79 .78 .07 .54 .34 .81 .85 .35 .03 .92 .18 .66 .75
.02 .63 .21 .17 .69 .64 .55 .22 .21 .82 .85 .07 .26 .13 .89 .58 .54 .16 .24 .15 .34 .85 .27 .84 .87	.71 .50 .80 .89 .56 .48 .22 .28 .06 .00 .01 .10 .07 .82 .04 .51 .54 .44 .82 .00 .61 .48 .64 .56 .26	.38 .15 .70 .11 .48 .61 .54 .13 .43 .91 .59 .63 .69 .36 .03 .62 .61 .65 .04 .69 .90 .18 .48 .13 .26	.43 .40 .45 .86 .98 .82 .78 .12 .23 .29 .69 .11 .15 .83 .80 .38 .18 .65 .18 .97 .37 .70 .15 .42 .57	.00 .83 .26 .91 .03 .06 .66 .24 .12 .27 .13 .29 .54 .19 .28 .85 .72 .13 .49 .21 .65 .65 .80 .39 .07
.03 .92 .18 .27 .46 .62 .95 .30 .27 .59 .08 .45 .93 .15 .22 .07 .08 .55 .18 .40 .01 .85 .89 .95 .66	.57 .99 .16 .96 .56 .37 .75 .41 .66 .48 .60 .21 .75 .46 .91 .45 .44 .75 .13 .90 .51 .10 .19 .34 .88	.30 .33 .72 .85 .22 .86 .97 .80 .61 .45 .98 .77 .27 .85 .42 .24 .94 .96 .61 .02 .15 .84 .97 .19 .75	.84 .64 .38 .56 .98 .23 .53 .04 .01 .63 .28 .88 .61 .08 .84 .57 .55 .66 .83 .15 .12 .76 .39 .43 .78	.99 .01 .30 .98 .64 .45 .76 .08 .64 .27 .69 .62 .03 .42 .73 .73 .42 .37 .11 .16 .64 .63 .91 .08 .25
.72 .84 .71 .14 .35 .88 .78 .28 .16 .84 .45 .17 .75 .65 .57 .96 .76 .28 .12 .54 .43 .31 .67 .72 .30	.19 .11 .58 .49 .26 .13 .52 .53 .94 .53 .28 .40 .19 .72 .12 .22 .01 .11 .94 .25 .24 .02 .94 .08 .63	.50 .11 .17 .17 .76 .75 .45 .69 .30 .96 .25 .12 .74 .75 .67 .71 .96 .16 .16 .88 .38 .32 .36 .66 .02	.86 .31 .57 .20 .18 .73 .89 .65 .70 .31 .60 .40 .60 .81 .19 .68 .64 .36 .74 .45 .69 .36 .38 .25 .39	.95 .60 .78 .46 .75 .99 .17 .43 .48 .76 .24 .62 .01 .61 .16 .19 .59 .50 .88 .92 .48 .03 .45 .15 .22
.50 .44 .66 .44 .21 .22 .55 .22 .15 .86 .96 .24 .40 .14 .51 .31 .73 .91 .61 .19 .78 .60 .73 .99 .34	.66 .06 .58 .05 .62 .26 .63 .75 .41 .99 .23 .22 .30 .88 .57 .60 .20 .72 .93 .48 .43 .89 .94 .36 .45	.68 .15 .54 .35 .02 .58 .42 .36 .72 .24 .95 .67 .47 .29 .83 .98 .57 .07 .23 .69 .56 .69 .47 .07 .41	.42 .35 .48 .96 .32 .58 .37 .62 .18 .51 .94 .69 .40 .06 .07 .65 .95 .39 .69 .58 .90 .22 .91 .07 .12	.14 .52 .41 .52 .48 .03 .37 .18 .39 .11 .18 .16 .36 .78 .86 .56 .80 .30 .19 .44 .78 .35 .34 .08 .72
.84 .37 .90 .61 .56 .36 .67 .10 .08 .23 .07 .28 .59 .07 .48 .10 .15 .83 .87 .60 .55 .19 .68 .97 .65	.70 .10 .23 .98 .05 .98 .93 .35 .08 .86 .89 .64 .58 .89 .75 .79 .24 .31 .66 .56 .03 .73 .52 .16 .56	.85 .11 .34 .76 .60 .99 .29 .76 .29 .81 .83 .85 .62 .27 .89 .21 .48 .24 .06 .93 .00 .53 .55 .90 .27	.76 .48 .45 .34 .60 .33 .34 .91 .58 .93 .30 .14 .78 .56 .27 .91 .98 .94 .05 .49 .33 .52 .29 .38 .87	.01 .64 .18 .39 .96 .63 .14 .52 .32 .52 .86 .63 .59 .80 .02 .01 .47 .59 .38 .00 .22 .13 .88 .83 .34
.53 .81 .29 .13 .29 .51 .86 .32 .68 .92 .35 .91 .70 .29 .13 .37 .71 .67 .95 .13 .93 .66 .13 .83 .27	.35 .01 .20 .71 .34 .33 .98 .74 .66 .99 .80 .03 .54 .07 .27 .20 .02 .44 .95 .94 .92 .79 .64 .64 .72	.62 .33 .74 .82 .14 .40 .14 .71 .94 .58 .96 .94 .78 .32 .66 .64 .85 .04 .05 .72 .28 .54 .96 .53 .84	.53 .73 .19 .09 .03 .45 .94 .19 .38 .81 .50 .95 .52 .74 .33 .01 .32 .90 .76 .14 .48 .14 .52 .98 .94	.56 .54 .29 .56 .93 .14 .44 .99 .81 .07 .13 .80 .55 .62 .54 .53 .89 .74 .60 .41 .56 .07 .93 .89 .30
.02 .96 .08 .45 .65 .49 .83 .43 .48 .35 .84 .60 .71 .62 .46 .18 .17 .30 .88 .71 .79 .69 .10 .61 .78	.13 .05 .00 .41 .84 .82 .88 .33 .69 .96 .40 .80 .81 .30 .37 .44 .91 .14 .88 .47 .71 .32 .76 .95 .62	.93 .07 .54 .72 .59 .72 .36 .04 .19 .76 .34 .39 .23 .05 .38 .89 .23 .30 .63 .15 .87 .00 .22 .58 .40	.21 .45 .57 .09 .77 .47 .45 .15 .18 .60 .25 .15 .35 .71 .30 .56 .34 .20 .47 .89 .92 .54 .01 .75 .25	.19 .48 .56 .27 .44 .82 .11 .08 .95 .97 .88 .12 .57 .21 .77 .99 .82 .93 .24 .98 .43 .11 .71 .99 .31
.75 .93 .36 .57. 83 .38 .30 .92 .29 .03 .51 .28 .50 .10 .34 .21 .31 .38 .86 .24 .29 .01 .23 .87 .88	.56 .20 .14 .82 .11 .06 .28 .81 .39 .38 .31 .57 .75 .95 .80 .37 .79 .81 .53 .74 .58 .02 .39 .37 .67	.74 .21 .97 .90 .65 .62 .25 .06 .84 .63 .51 .97 .02 .74 .77 .73 .24 .16 .10 .33 .42 .10 .14 .20 .92	.96 .42 .68 .63 .86 .61 .29 .08 .93 .67 .76 .15 .48 .49 .44 .52 .83 .90 .94 .76 .16 .55 .23 .42 .45	.74 .54 .13 .26 .94 .04 .32 .92 .08 .09 .18 .55 .63 .77 .09 .70 .47 .14 .54 .36 .54 .96 .09 .11 .06
.95 .33 .96 .22 .00 .90 .84 .60 .79 .80 .46 .40 .62 .98 .82 .20 .31 .89 .03 .43 .71 .59 .73 .05 .50	.18 .74 .72 .00 .18 .24 .36 .59 .87 .38 .54 .97 .20 .56 .95 .38 .46 .82 .68 .72 .08 .22 .23 .71 .77	.38 .79 .58 .69 .32 .82 .07 .53 .89 .35 .15 .74 .80 .08 .32 .32 .14 .82 .99 .70 .91 .01 .93 .20 .49	.81 .76 .80 .26 .92 .96 .35 .23 .79 .18 .16 .46 .70 .50 .80 .80 .60 .47 .18 .97 .82 .96 .59 .26 .94	.82 .80 .84 .25 .39 .05 .98 .90 .07 .35 .67 .72 .16 .42 .79 .63 .49 .30 .21 .30 .66 .39 .67 .98 .60

ii. Sample Station Location

This section describes the method for determining the station number for each sample location. This method may be adjusted to locate from one to four samples. Keep a written record of the computations in the project file. Use the random numbers determined in section **.125** C (i).

Example: For aggregate base gradations, select four (4) random tests for 10,000 tons. Assume a 6 inch layer, 52 feet in width and 135 pounds per cubic foot maximum density. The four random numbers selected are the 38^{th} through the 41^{st} (.84, .18, .79 and .75). The beginning station is 10+50.

a. Calculate tons per lineal feet and total lineal feet.

Tons per lineal foot =

$$\frac{\text{Length} \times \text{Width} \times \text{Thickness} \times \text{Maximum Density}}{2{,}000}$$

Where: Length, Width and Thickness are in units of feet and
Maximum Density is in units of pounds per cubic foot.

Ton per lineal foot = $\frac{1 \times 52 \times \frac{6}{12} \times 135}{2{,}000} = 1.755$

Total Lineal Feet =

$$\frac{10{,}000}{1.755} = 5{,}698 \text{ linear feet}$$

b. Calculate length and starting station for each sublot.

Four (4) sublots.

$$\frac{5{,}698}{4} = 1{,}425 \text{ feet} = 14 + 25 \text{ Stations per sublot}$$

1 Road Station = 100 feet

(Stationing for sublots should be rounded to the nearest foot)

Starting Station for Sublot 1 from 10+50 to 24+75
Starting Station for Sublot 2 from 24+75 to 39+00
Starting Station for Sublot 3 from 39+00 to 53+25
Starting Station for Sublot 4 from 53+25 to 67+50

c. Calculate stationing for the four samples in each sublot.

Table B 5-692.125 denotes the distance from starting station to the sample location.
Table C 5-692.125 denotes station for each sample.

Table 5-692.125-B

Sample Number	Random Number		Length of Sublot		Distance from Starting Station
1	.84	×	1,425 feet	=	1,197 feet
2	.18	×	1,425 feet	=	256 feet
3	.79	×	1,425 feet	=	1,126 feet
4	.75	×	1,425 feet	=	1,069 feet

Table 5-692.125-C

Sample Number	Beginning Station		Random Distance		Sample Location
1	10+50	+	1,197 feet (11+97 Sta)	=	Station 22+47
2	24+75	+	256 feet (2+56 Sta)	=	Station 27+31
3	39+00	+	1,126 feet (11+26 Sta)	=	Station 50+26
4	53+25	+	1,069 feet (10+69 Sta)	=	Station 63+94

Obtain approximately one-third (⅓) of the sample from the center, and one-third (⅓) each of the sample from the ¼ points, and combine into one sample. Then split for 2 tests, see Figures 5-692.125-1 and 2.

Four (4) Equal Sublots

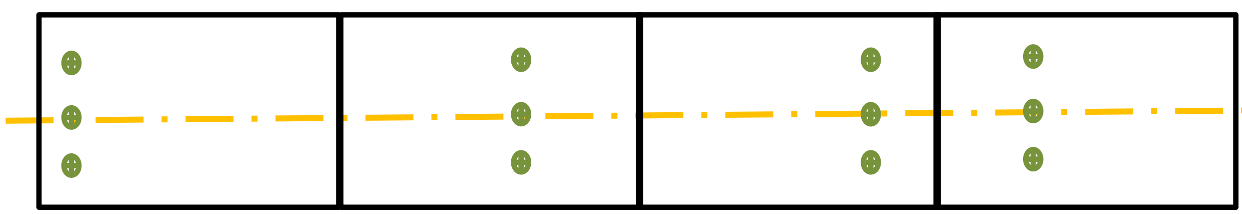


Figure 5-692.125-1

One (1) random number per sublot with three (3) collection points per sample

Obtain approximately one-third (⅓) of sample from each location (i.e. at tip of arrow)

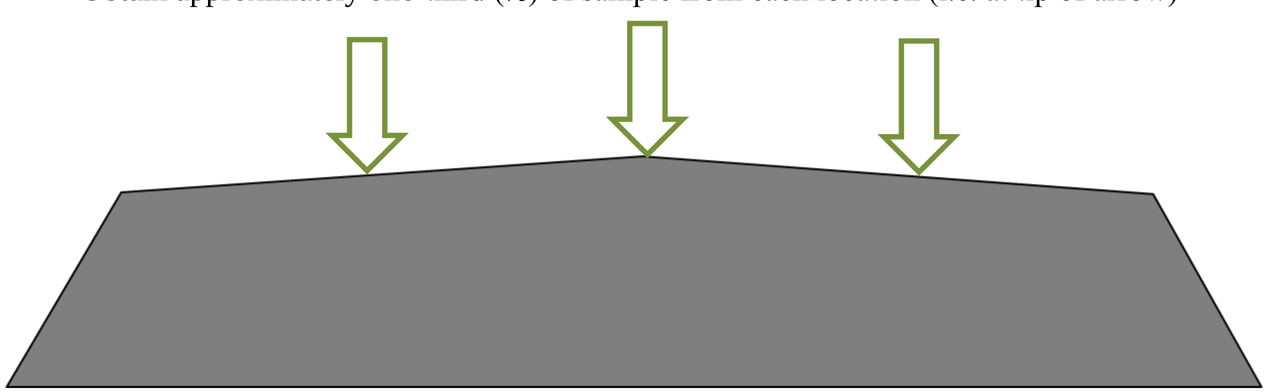


Figure 5-692.125-2

iii. Truck Load Count Sample Method

Determine Lot size and random number per above. Divide Lot size by truck size to obtain total number of trucks required per Lot. Divide the Lot size by the number of sublots to determine the sublot size. Apply random numbers to the sublot size to determine, which truck to sample. Take sample from the road after spreading, but before compaction at the location where the material from that truck was placed. **Not from truck box.**

Example: The project is under construction at several locations. Trucks hauling approximately 21 tons each will deliver 8,430 tons (Plan Quantity) of Class 5 aggregate base.

8,430 tons ÷ 21 ton/truckload (average) = 401.4 loads ≈ 401 loads

401 loads/4 ≈ 100 loads/sublot

Take samples from the approximate area these trucks place material. Table 5-692.125-D denotes the truck to be sampled.

Table 5-692.125-D

Sample Number	Random Number		Sublot Quantity		Truck Number
1	.84	×	100 Loads	=	Load # 84
2	.18	×	100 Loads	=	Load # 100 + 18 = 118
3	.79	×	100 Loads	=	Load # 200 + 79 = 279
4	.75	×	100 Loads	=	Load # 300 + 75 = 375

iv. Modifications in the Plan quantity.

Modify testing and sampling protocol for increases in Plan quantities as follows:

Time Plan Quantity Increased	Testing and Sampling
Before Collection of first sample.	Reorder sampling to account for additional quantity.
After Collection of first sample, but before sampling is complete.	Complete testing of current Lot, and then reorder the sampling using the remaining quantity.
After collection of all original Plan quantity samples.	Order sampling for additional quantity.

.130 Non-Random Sampling

When sampling materials for laboratory or field tests by the non-random sampling method, locate the sample in the area least likely to meet specifications. Inform the Contractor of any failure as soon as posible, but no later than 24 hours after obtaining test results. Have the Contractor remove or modify failing materials, and retest in areas which are least likely to meet specifications.

.135 Sampling for Proctor (Moisture Density Test)

A. Grading Construction

Samples required for the proctor test should represent the material being placed. Fifty pounds of material is necessary for a proctor test.

Each sample tested should be identified by source (pit number, pit name or station), depth, soil classification, and test results. Save a portion of each sample from each major soil type, at about optimum moisture content, in a transparent container for use as a reference. Use the soil's triangle, located in the section 5-692.600 of this manual, as a guide in soil comparison. Label this sample with the assocatied soil classification and test results.

B. Base, Subbase, and Surfacing Construction

Moisture-Density properties of base and subbase aggregates vary as the gradation of the aggregate varies.

Record the sample location.

Sample subbase, base or shouldering aggregate from one location on the road after spreading, but before compaction.

5-692.140 Splitting

5-692.141 Quartering Method of Sample Size Reduction

A. General

The quartering method of sample size reduction works best on damp material. Quarter sample on a concrete slab, new plywood or sheet metal deck or similar smooth, clean floor area, about 4' × 4'.

B. Procedure

(See Figures 5-692.141-1-4)

Step 1 Dump the sample onto the clean floor area.

Step 2 By shoveling, move the sample to an adjacent area and form a continuous cone by emptying the shovel directly over the center (Figure 1).

Step 3 Repeat the coning until the sample is thoroughly mixed.

Step 4 With a shovel or other device, make a clean pass bisecting the cone vertically (Figure 2).

Step 5 Draw the halves away from each other.

Step 6 Bisect the halves (Figure 3).

Step 7 Combine diagonally opposite quarters to form a sample (Figure 4). If the sample is still larger than desired repeat Step 1 thru 7. In this case, piles B & D were combined.

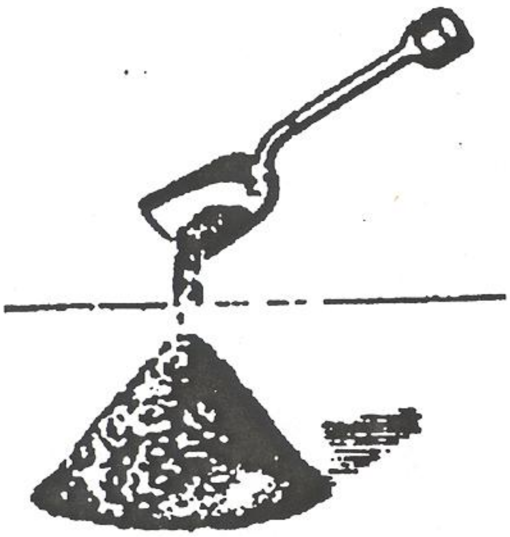


Figure 1

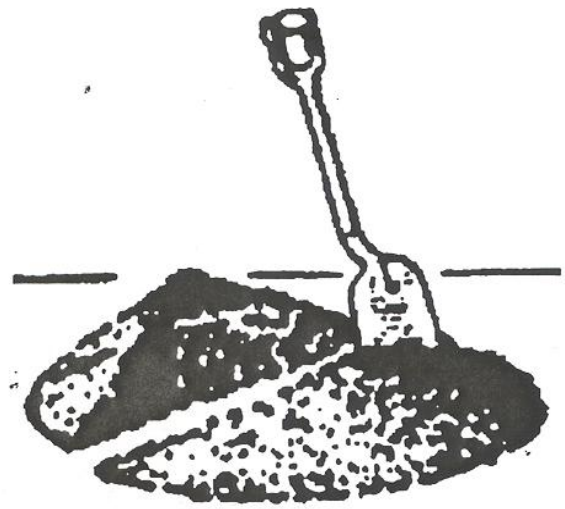


Figure 2

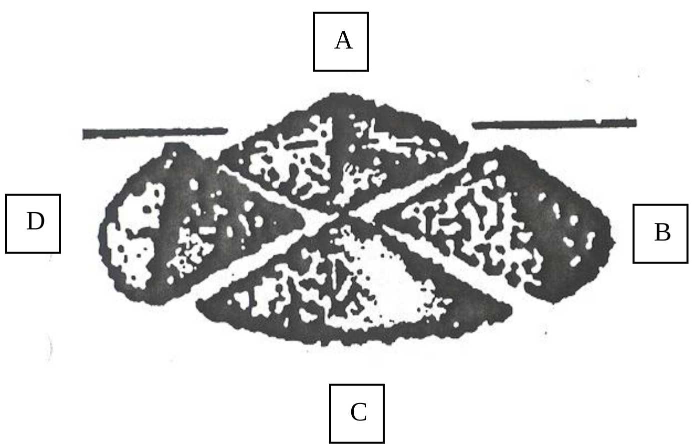


Figure 3

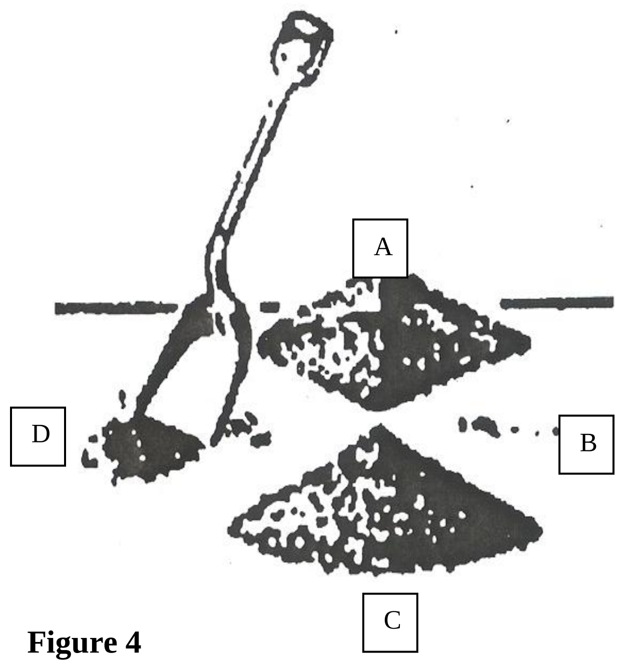


Figure 4

Figures 5-692.141 (1-4)

5-692.142 Ring and Cone Method of Sample Size Reduction

A. The ring and cone method is usually used for large quantities of material and requires more working area than the other sample reduction methods. The radius of the ring is determined by the weight of the sample and should be equal in feet to 1/40th of the sample weight in pounds. For instance, a 400 lb. sample requires a radius of 10 ft. (20 feet in diameter).

B. Procedure

Dump the entire sample onto the clean floor area. By shoveling, move the sample to an adjacent area and form a continuous cone by emptying the shovel directly over the center. Repeat the coning until the sample is mixed thoroughly (Figure 5-692.1421).

Step 1 Place a rake or trowel at the top of the cone, push down and pull a portion of sample out to the required radius (Figure 5-692.142-2).

$$Required\ Radius\ (ft) = \frac{Weight\ of\ Sample\ in\ Pounds}{40\ Pounds\ per\ foot}$$

Step 2 Move to a position opposite Step 1 and repeat Step 1 (Figure 5-692.142-3).

Step 3 and Step 4 Repeat Steps 1 and 2 at 90^0 (Figures 5-692.142-4 and 5-692.142-5) from the original position of Steps 1 and 2.

Step 5 Continue Steps 1, 2, 3 and 4 (Figure 5-692.142-6) until the entire sample is evenly windrowed into a ring (Figure 5-692.142-7).

Step 7 and Step 8 Collect sample by cutting the ring at opposite points with a shovel (Figure 5-692.142-8). (A sample consists of material removed from two or more pairs of opposite sections of the ring (Figure 5-692.142-9).)

Figure 1

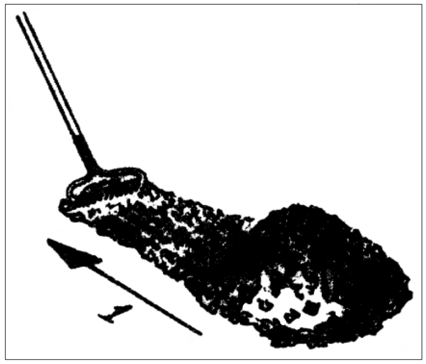


Figure 2

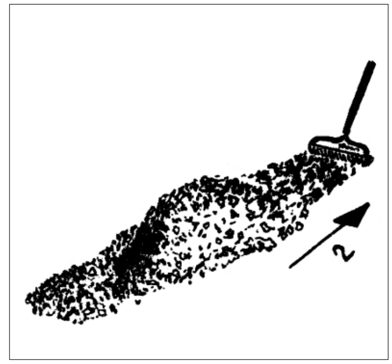


Figure 3

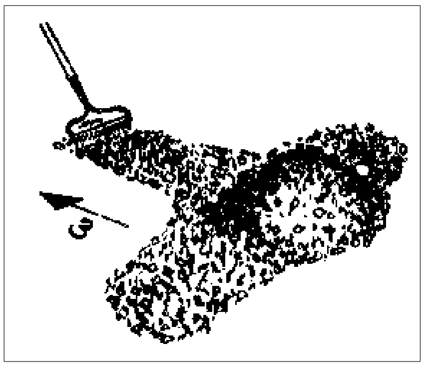


Figure 4

Figure 5

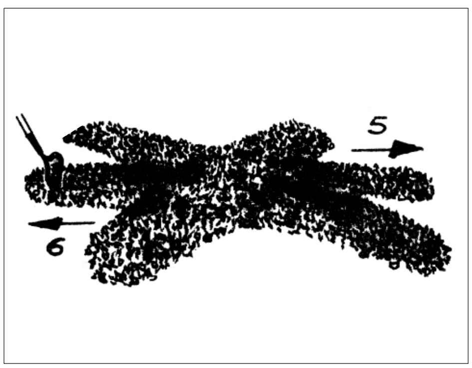


Figure 6

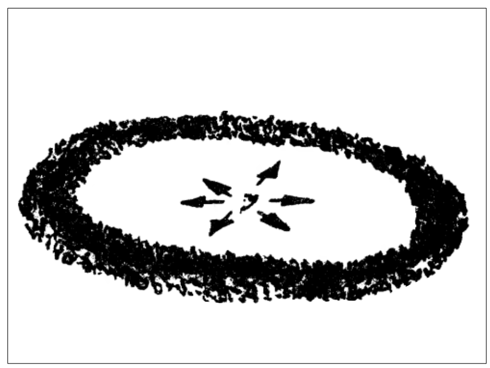


Figure 7

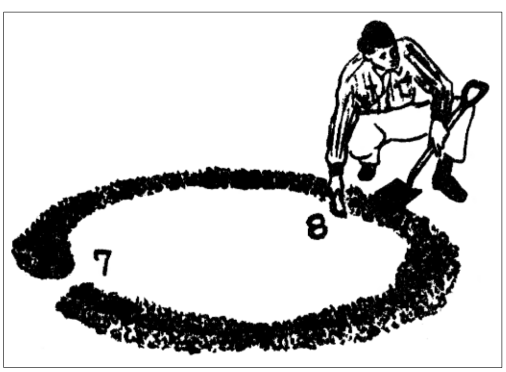


Figure 8

Figure 9

Figures 5-692.142-1-9

5-692.143 Riffle Splitter Method of Sample Size Reduction

A. General

A sample splitter consists of a series of chutes running in alternately opposite directions. When a sample is poured into the chutes, one-half of the sample runs off in each direction into collection pans. The sample splitter works best with air-dry material. Split the sample when the material is near optimum moisture, so that material is free flowing, and minimal dusting occurs.

B. Procedure

See Figures 5-692.143-1 and 2

Step 1 Place one collection pan on each side of the splitter allowing the chutes to extend into the pans.

Step 2 Thoroughly blend the sample prior to splitting to reduce sample segregation.

Step 3 Pour the sample through the chutes (Figure 5-692.143-1), while ensuring that the sample does not pile up in the hopper.

Step 4 Check sample for uniformity, recombine sample and repeat steps 1-3, if sample is not uniform.

Step 5 The sample may be split into smaller sizes by re-splitting the material collected on each side of the splitter, following Steps 1 through 4 above (Figure 5-692.143-2).

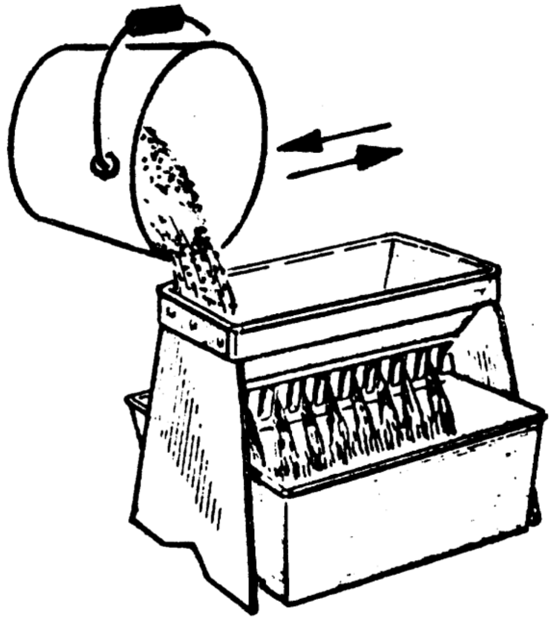


Figure 5-692.143-1

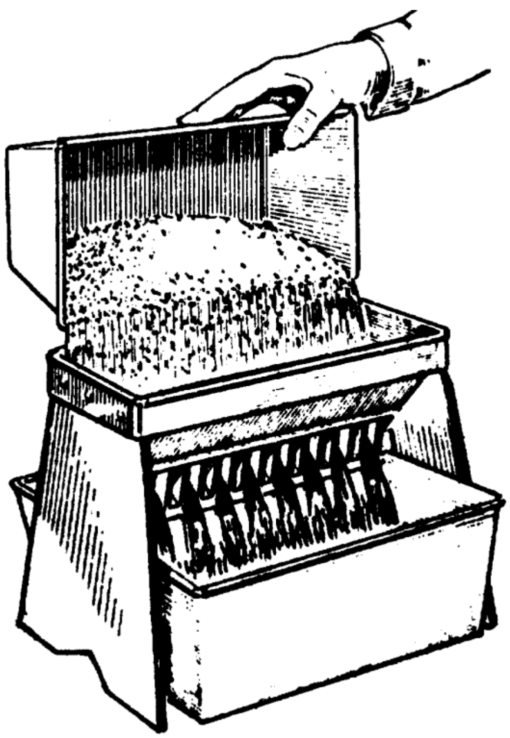


Figure 5-692.143-2

Figures 5-692.143-1 & 2

5-692.150 Independent Assurance (IA) Sampling and Testing

Independent Assurance sampling and testing is required on all Federal Aid, State Aid and County Federal Aid Projects. Assurance sampling is the direct responsibility of the District Materials Engineer.

The purpose of this sampling is to verify the inspector's sampling, testing procedures and equipment. The project personnel are required to notify the district materials office when any work requiring Independent Assurance sampling has begun. The project personnel should ensure that some scheduling lead time is provided.

Procedure:

The District Independent Assurance Inspector is required to review the inspector’s sampling, testing procedures and equipment; and to obtain laboratory samples. The Independent Assurance Inspector will record findings.

The following procedures are recommended to obtain the maximum benefit.

A. Any Independent Assurance test or sampling procedures should be performed by the project personnel assigned to that particular phase of the work.

B. The equipment used and procedures followed during Independent Assurance sampling and testing should be the same as that used during the routine sampling and testing requirement on the job.

C. If the procedure followed or equipment used does not conform to the applicable standard, note the fact on the report and advise the inspector of the corrections required for subsequent tests.

D. Independent Assurance gradation test samples must be split samples from field gradation samples so that the field and lab results can be compared.

E. Report the test result and the action taken by the inspector, when an Independent Assurance test is observed and the given measurement does not meet requirements.

F. If it becomes evident that a required Independent Assurance test or sample cannot be obtained, report the type of construction, sample standard involved and the reasons for not obtaining the test or sample.

Investigate any deviation, between an Independent Assurance test result and a companion test result, outside the tolerances stated in Table 1003C of the MnDOT Laboratory Manual.

5-692.160 Sample Identification Card

A. Samples submitted to the laboratory must contain a sample identification card properly protected against moisture and soiling. A zip-lock type sandwich bag works well.

B. The following is an example of a properly completed identification card:

1. **"Field Identification"**
This identifier is generated by the field inspector to assist with tracking the sample.

2. **"Spec."**
Include both the specification number and class of material.

3. **"S.P."**
Submit all the samples under the lowest project number.

4. **"Submitted by"**
Enter the name of the submitter. If the sample is an Independent Assurance (IA) Sample, include the IA's name, and write "IA Sample" on the card.

5. **"Proj. Engr."**
Enter the name of the project engineer.

6. **"Type of material and use"**
Enter what the material is to be used for and the specification.

Example: Base (2211)
Shouldering (2221)
Subgrade Soil (2105)

7. **"Mix Proportions"**
Report the composition of virgin and recycled aggregates by type (e.g., % natural gravel, % quarried carbonates, % quarried class A, % RAP, %RCP, % glass, etc.).

8. **"Pit No."**
Give the Pit Number for 3138 samples and the pit number (or owner's name) for 3149 samples.

9. **"Source"**
Provide the Pit name.

10. **"Location"**
Location of pit (i.e., either geographic, as in illustration, or legal description with Section, Town and Range).

11. **"Sample taken from"**
Stationing of sample location.

12. **"Tests required"**
Example: Gradation, Shale, Proctor, LA Rattler, etc.

13. **"Remarks"**

If it is a split gradation sample, write the field gradation results on the back of the card. Also, include any observations or information that would assist with evaluating the sample test results. Include the gradation specification requirements of sample.

5 692.170 Documentation

The Engineer is responsible for maintaining a file with the following items:

Form	Description
G&B-001 [TP 02115]	Grading and Base Report (Preliminary and Final)
G&B-104 [TP 24346]	Certification of Aggregates (include all contractor gradation and quality test reports)
–	Worksheet with computations for sample locations and Lot sizes.
G&B-101 (English) or G&B-102 (Metric) [TP 02402]	Sieve Analysis (for each verification test sample)
G&B-002 [TP 02154]	Random Sampling Acceptance (for each Lot)
–	Materials Certification Project Compliance Summary
–	Documentation of Random Number Selection

5-692.200 METHODS OF TESTING

5-692.201 TEST FOR SHALE IN AGGREGATE (By Pick Method)

A. Scope

1. The lithological summary method is used with aggregates to determine the percentage of various rock types and especially the deleterious varieties. This method separates shale by visual and hand sorting.

2. See Mn/DOT Laboratory Manual Section 1209 for the proper procedure.

5-692.202 TEST FOR SHALE IN AGGREGATE (By Float Method)

A. Scope

1. The method of test covers a procedure for the approximate determination of shale in aggregate. This method separates, along with the shale, other particles of low specific gravity or relatively high surface area such as iron oxides, soft particles and other spall material.

B. Test for shale in coarse aggregate (plus 4.75mm) [plus No. 4].

1. Equipment.
   a. Torsion or beam balance having a capacity of at least 2500 grams.
   b. Shale bath and basket (Mn/DOT model).
   c. Strainers, two or more, having openings not larger than 2.36mm (No. 8) mesh.
   d. Stove or oven, drying pans, and large mixing spoon.
   e. Zinc chloride.
   f. Hydrometer.
   g. "Sand bath", if stove is used. A sand bath is constructed by placing a layer of dry sand 25 mm to 40 mm (1" to 1½") in thickness in a metal pan. The sample in the drying pan is then placed on the sand bed to dry.

2. Sample.
   a. Select approximately 2500 grams of aggregate retained on the 4.75mm (No. 4) sieve by quartering or other suitable method to insure representation.
   b. Dry the sample to a constant weight either in an oven or over an open burner at a temperature not to exceed 110ºC (230ºF). The restriction in temperature is made to prevent the shale particles from "exploding" because of excessive heat. When drying the sample over an open burner, a sand bath must be used and the heat applied cautiously in order to keep the sample under 110ºC (230ºF).
   c. Cool the sample, weigh and **record this weight** to the nearest 0.1 gram.

3. Zinc chloride solution.
   Caution: Zinc chloride should not come into direct contact with the skin. Equipment should be kept clean because of the corrosive action of the solution.
   a. Place 24 kg (50 lb.) of zinc chloride (Zn Cl_2) in the shale bath, add approximately 6.6 (7 quarts) liters of water, and stir until the zinc chloride is dissolved.
   b. Allow the solution to cool to room temperature. This will take approximately 12 hours.
   c. Adjust the specific gravity to 2.00 ± 0.02, either by adding more water if the specific gravity is too high, or adding zinc chloride if too low.

4. Procedure.
   a. Place the coarse aggregate in the wire basket and lower it into the tank containing the solution.
   b. Stir sample vigorously with a large mixing spoon for one minute.
   c. Skim off floating particles within one minute after stirring ceases.
   d. Thoroughly wash the removed particles to remove the zinc chloride.
   e. Dry sample at a temperature not to exceed 110ºC (230ºF).
   f. Weigh and record weight to nearest 0.1 gram.

5. Calculations:
   a. The percent shale is calculated as follows:
      Percent Shale =

$$\frac{\text{Dry wt. of shale}}{\text{Dry wt. of total sample}} \times 100$$

C. Test for shale in fine aggregate - minus 4.75mm (minus No. 4).

1. Equipment.
   a. Torsion or beam balance.
   b. 600 µm (No. 30) sieve
   c. Glass beakers or jars - approx. one liter size (one quart size).
   d. Strainers, two or more having a mesh finer than a 600 µm (No. 30) sieve.
   e. Stove or oven, drying pans, and large mixing spoon.
   f. Iced–tea spoon, with spoon bent at right angle to the handle.
   g. Zinc chloride solution having a specific gravity of 2.00 ± 0.02.
   h. Hydrometer.

2. Sample.
   a. Select a 200 to 300 gram sample from the material passing the 4.75mm (No. 4) sieve by one of the following methods: sample splitter, quartering or ring.
   b. Dry the sample to a constant weight either in an oven or over an open burner at a temperature not to exceed 110ºC (230ºF). If the sample is dried over an open burner, a “sand bath” must be used to control the temperature.

c. Cool the sample, weigh and **record this weight** to the nearest 0.1 gram.

d. Screen the sample over the 600 µm (No. 30) sieve and only that portion retained on the 600 µm (No. 30) sieve is saved for the test.

3. Zinc chloride solution.
A solution of zinc chloride is prepared as described in the procedure for determining percent of shale in coarse aggregate.

4. Procedure.

a. Fill a glass beaker or jar approximately two-thirds full with zinc chloride solution and pour the sample (only the plus 600 µm [No. 30] material) into the solution. As the sample is added, stir the solution vigorously with an ice tea spoon until all of the sample is in suspension.

b. Allow the sample to settle until there is a definite cleavage plane between the rising shale and the settling sand (approximately 30 seconds).

c. Decant the solution over a strainer until the sand appears near the lip of the beaker. Care must be taken that only the floating particles are poured off with the liquid.

d. When large quantities of shale are encountered, the processes may need to be repeated. (Note: the sample shall not be in contact with the zinc chloride solution for more than 2 ½ minutes during the test).

e. Thoroughly wash the material retained on the strainer to remove the zinc chloride.

f. Dry the sample at a temperature not to exceed 110ºC (230ºF).

g. Weigh and record weight to nearest 0.1 gram.

5. Calculations:

Percent Shale =

$$\frac{\text{Dry wt. of shale}}{\text{Dry wt. of total sample}} \times 100$$

<u>Calculations for percent of shale in total sample</u>:

A = percent shale in aggregate retained on the 4.75mm (No. 4) sieve
B = percent shale in aggregate passing the 4.75mm (No. 4) sieve
C = percent of total sample retained on the 4.75mm (No. 4) sieve
D = percent of total sample passing the 4.75mm (No. 4) sieve

Percent Shale in Total Sample =

$$(A \times \frac{C}{100}) + (B \times \frac{D}{100})$$

5-692.203 FIELD TEST TO DETERMINE THE PERCENT OF CRUSHING (BY CONVEYOR BELT METHOD)

A. Crushing will be required for Classes 5 and 6 Base Aggregate and for Aggregate Bedding and Stabilizing Aggregate. For these classes of aggregate, crushing will be required for all stones larger than the maximum size permitted by the gradation requirements and which will pass a grizzly or bar grate having parallel bars spaced 200mm (8 inches) apart. However, rejection of oversize material will be permitted by the Engineer when excessive crushing results in an unsatisfactory gradation. This test is used to determine compliance with the crushing requirements of specification 3138 at the time that the aggregate stockpile is being produced.

In the production of Class 6 aggregate, there shall be at all times not less than 15 percent of material which shall be crushed. In the production of Class 5, Aggregate Bedding and Stabilizing Aggregate, there shall be at all times not less than 10 percent of material which shall be crushed. The percentage of crushing shall be determined by the weight of the material retained on a 19mm (3/4”) sieve.

B. The required apparatus is listed below:

1. Containers—Pails suitable for collecting and weighing gravel samples.
2. 27.2 kg (60 lb.) capacity dairy scale with decimal graduations in tenths of a kilogram (lb.) (Interpolate reading to the nearest 0.05 kg.) [lb.]
3. Sieve— Nominal Maximum size for the class of aggregate being produced (19 mm sieve) [3/4” sieve].
4. Square nosed shovel.

C. Test Sample

The sample shall be obtained at least once each day from the belt which conveys the material from the trap to the crusher. The sample shall be taken at a time when pit operations are normal. Stop the belt. Select a representative section on the belt and remove all of the material from the selected section. This sample should weigh approximately 15 kilograms (30 lb.).

D. Procedure

Step 1. Air dry the sample to reduce the amount of fines that cling to the oversize material.

Note: Fines will not usually cling to the oversize material if the moisture content is approximately 3% or less.

Step 2. Weigh the total sample (should weigh approximately 15 kg [30 lb.]). Record weight (A) on form 02463. (See Fig. 1 5-692.204).

Step 3. Screen the sample over the maximum required sieve size (19mm [3/4”] sieve). Use breaker sieves as needed.

Step 4. Determine the weight of aggregate retained on the 19mm (3/4”) sieve. Record weight (B).

Step 5. Compute the percent of crushing using the following calculations:

A. Weight of Total Sample ....kg

B. Base Aggregate, Weight Retained on 19mm (3/4”) Sieve ....kg

Percent Crushing (B)/(A) x 100 = %

Minimum Crushing Required %

E. Example (Metric) – See Fig. 1M 5-692.204

Given: 3138 Class 5 Aggregate

Maximum Aggregate Sieve Size = 19mm sieve

Minimum Crushing Required = 10%

Sample:

a. Weight of Total Sample = 14.85 kg (A)

b. Base Aggregate, Weight Retained on 19 mm Sieve = 2.79 kg (B)

Calculations:

$$\frac{(B)}{(A)} \times 100 = \frac{2.79}{14.85} \times 100 = 18.8\%$$

Therefore meets requirements.

Example (English) – See Fig. 1E 5-692.204

Given: 3138 Class 5 Aggregate

Maximum Aggregate Sieve Size = 3/4” sieve

Minimum Crushing Required = 10%

Sample:

a. Weight of Total Sample = 30.6 lbs. (A)

b. Base Aggregate, Weight Retained on 3/4” Sieve = 5.6 lbs. (B)

Calculations:

$$\frac{(B)}{(A)} \times 100 = \frac{5.6}{30.6} \times 100 = 18.3\%$$

Therefore meets requirements.

F. Application of the test

Because the samples for this test are taken before the final mixing of the aggregate, it can be anticipated that there will be variations in the percent of crushing. It can also be anticipated that after final mixing has been accomplished to meet the gradation requirements that these variations will have been eliminated in the final product. For this reason, some tolerance can be allowed. An occasional deviation of up to 2% can be allowed. However, the average percent of crushing of all the material tested for the project shall not be less than the specified percent. If a test exceeds the allowable tolerance, the contractor should be informed immediately and adjustments made to obtain the required amount of crushing by possibly adding stones or crushed rock from another source. After operations have been adjusted, a check test should be made.

G. Reports

Under remarks on Mn/DOT TP-02115-02 (Monthly Grading and Base Report) or the ConLab monthly report indicate the number of tests required, the number made and the average percent of crushing.

5-692.204 DETERMINATION OF PERCENT OF CRUSHING (BY CRUSHED PARTICLE COUNT OF PLUS 4.75MM (NO. 4) MATERIAL)

A. This method is intended to be used only when the material has been crushed into a stockpile before an inspector was assigned to the project. For the purpose of this method, crushed particles are defined as material that has at least one fractured face.

This method involves counting the particles of plus 4.75mm (No. 4) material having one or more fractured faces and computing the percent of crushing in the total sample.

In the production of Class 6 aggregate, there shall be at all times not less than 15 percent of material which shall be crushed. In the production of Class 5, Aggregate Bedding and Stabilizing Aggregate, there shall be at all times not less than 10 percent of material which shall be crushed.

B. Procedure

Step 1. Obtain a representative sample weighing approximately 15 kg (30 lbs.) from the prepared stockpile. Air dry the sample to reduce the amount of fines that cling to the material.

> **Note:** Usually, fines will not cling to the material if the moisture content is approximately 3% or less.

Step 2. Determine the Total Weight of Sample. Record weight (A). (See Fig. 1M or 1E, 5-692.204).

Step 3. Determine the sample's gradation in accordance with the method described in 5-692.210 to verify that the aggregate meets specification requirements. Screen the sample and reserve the material retained on the 19mm (3/4”), 9.5mm (3/8”) and 4.75mm (No. 4) sieves.

Step 4. Determine the weight of aggregate passing the 25mm (1”) sieve and retained on the 4.75mm (No. 4) sieve. Record weight (B).

Step 5. By using the following formula, compute and record the percent of aggregate retained on the 4.75mm (No. 4) sieve (C):

$$\text{\% Ret. on 4.75mm (No. 4) sieve (C)} = \frac{(B)}{(A)} \times 100$$

Step 6. Determine the weight of aggregate passing the 25mm (1”) sieve and retained on the 9.5mm (3/8”) sieve. Record weight (D).

Step 7. Determine the weight of aggregate passing the 9.5mm (3/8”) sieve and retained on the 4.75mm (No. 4) sieve. Record weight (E).

> **Note:** (D) + (E) should equal (B).

Step 8. By using the following formula, compute and record the percent of aggregate retained on the 9.5mm (3/8”) sieve (F):

$$\%\ \text{Ret. on 9.5mm (3/8”) sieve (F)} = \frac{(D)}{(B)} \times 100$$

Step 9. By using the following formula, compute and record the percent of aggregate passing the 9.5mm (3/8”) sieve and retained on the 4.75mm (No. 4) sieve (G):

$$\%\ \text{9.5mm (3/8”) to 4.75mm (No. 4) sieve (G)} = \frac{(E)}{(B)} \times 100$$

Note: (F) + (G) should equal 100.0%

Step 10. Combine the material retained on the 19mm (3/4”) and 9.5mm (3/8”) sieves. Quarter the sample to obtain a representative sample weighing about 1500 grams. Do not attempt to select an exact predetermined weight. Record this as the Weight of Sample Passing the 25mm (1”) sieve and retained on 9.5mm (3/8”) (J).

Step 11. From the sample passing 25mm (1”) sieve and retained on 9.5mm (3/8”) sieve (I), collect and weigh all of the particles that have at least one fractured face. Record weight (K).

Step 12. Quarter the material which passes the 9.5mm (3/8”) sieve and is retained on the 4.75mm (No. 4) sieve to obtain a representative sample weighing between 450 to 550 grams. Record weight (L).

Step 13. From the sample 9.5mm (3/8”) to 4.75mm (No. 4) sieves, collects and weigh all of the particles that have at least one fractured face. Record weight (M).

Step 14. By using the following formula, compute the Percent of Crushed Particles in the Total Sample (N):

$$\left(\left[\frac{(K)}{(J)} \times (F)\right] + \left[\frac{(M)}{(L)} \times (G)\right]\right)\left(\frac{(C)}{70}\right)$$

Note: 70 is a constant because it is assumed that 30% of the crushed material passes a 4.75mm (No. 4) sieve.

C. Example (see Fig. 1M or 1E 5-692.204)

D. Application of the test
Because the samples for this test are usually taken before the final mixing of the aggregate, it can be anticipated that there will be variations in the percent of crushing.

It can also be anticipated that after final mixing has been accomplished to meet the gradation requirements that these variations will have been eliminated in the final product. For this reason, some tolerance can be allowed. An occasional deviation of up to 2% can be allowed. However, the average percent of crushing of all the material tested for the project shall not be less than the specified percent. If a test exceeds the allowable tolerance, the contractor should be informed immediately and adjustments made to obtain the required amount of crushing by possibly adding stones or crushed rock from another source. After operations have been adjusted, a check test should be made.

E. Reports

Under remarks on Mn/DOT TP-02115-02 (Monthly Grading and Base Report) or the ConLab monthly report indicate the number of tests required, the number made and the average percent of crushing.

TP-02463 (4/2002)

Minnesota Department of Transportation
Office of Materials Engineering

Percent Crushing Report

S.P.: 0242-47	Test No. 19	Date: 4-30-02	Engineer G. Helpus
Contractor: Build Anything, Inc.		Aggregate Source: Van Trisen Pit	
Type or Class of Aggregate Class 5 - 3138		Pit Location (Legal) #031538	
Sample From: Belt & Stockpile		Size of Grizzly: 8"	

Method 1: Percent Crushing (Conveyor Belt)

(A) Weight of Total Aggregate Sample: 30.6 kg lbs

(B) Aggregate Weight Retained on 19 mm (3/4") Sieve 5.6 kg lbs

Percent Crushing (B)/(A) x 100% 18.3 %

Minimum % Crushing Required 10.0 %

Method 2: Percent Crushing (Particle Count)	
	Specification's Maximun Aggregate Size 19 mm (3/4 in.)
(A) Total Weight of Sample	30.6 kg lbs
(B) Weight of Sample Ret. On 4.75 mm (#4) Sieve	10.2 kg lbs
(C) Percent Ret. On 4.75 mm (#4) Sieve = (B/A) x 100	33.3 %
(D) Weight of Sample Passing the 25 mm (1 in.) Sieve and Ret 9.5 mm (3/8 in.) Sieve	4.8 kg lbs
(E) Weight of Sample 9.5 mm (3/8 in.) to the 4.75 mm (#4) Sieve	5.4 kg lbs
(F) % Retained on 9.5 mm (3/8 in.) Sieve = D/B x 100	47.1 %
(G) % 9.5 mm (3/8 in.) to the 4.75 mm (#4) Sieve = E/B x 100	52.9 %
(H) TOTAL	100.0 %
(J) Weight of Sample Passing the 25 mm (1 in.) Sieve and Ret 9.5 mm (3/8 in.) Sieve	1805 gms
(K) Weight of Cr. Sample Passing the 25 mm (1 in.) Sieve and Ret 9.5 mm (3/8 in.) Sieve	592 gms
(L) Weight of Sample 9.5 mm (3/8 in.) to the 4.75 mm (#4) Sieve	516 gms
(M) Weight of Cr. Sample 9.5 mm (3/8 in.) to the 4.75 mm (#4) Sieve	225 gms
(N). Percent Cr. Part. In Total Sample [(K/JxF) + (M/L x G)] x [C/70]	18.3 %
Minimum % +#4 Crushed Particles Required	10.0 %

See Grading and Base Manual Fig 1M or 1 E 5-692.204

Remarks:

cc: Project File

Fig. 1E 5-692.204

TP-02463 (4/2002)

Minnesota Department of Transportation
Office of Materials Engineering

Percent Crushing Report

S.P.: 0242-47	Test No. 19	Date: 5-21-02	Engineer Minnie Daht
Contractor: Webuildem, Inc.		Aggregate Source: Yohnson Pit	
Type or Class of Aggregate Class 5 - 3138		Pit Location (Legal) #2704	
Sample From: Belt & Stockpile		Size of Grizzly: 200mm	

Method 1: Percent Crushing (Conveyor Belt)

(A) Weight of Total Aggregate Sample: 14.85 (kg)(lbs)

(B) Aggregate Weight Retained on 19 mm (3/4") Sieve 2.79 (kg)(lbs)

Percent Crushing (B)/(A) x 100% 18.8 %

Minimum % Crushing Required 10.0 %

Method 2: Percent Crushing (Particle Count)

	Specification's Maximun Aggregate Size 19 mm (3/4 in.)
(A) Total Weight of Sample	14.85 (kg)(lbs)
(B) Weight of Sample Ret. On 4.75 mm (#4) Sieve	4.95 (kg)(lbs)
(C) Percent Ret. On 4.75 mm (#4) Sieve = (B/A) x 100	33.3 %
(D) Weight of Sample Passing the 25 mm (1 in.) Sieve and Ret 9.5 mm (3/8 in.) Sieve	2.35 (kg)(lbs)
(E) Weight of Sample 9.5 mm (3/8 in.) to the 4.75 mm (#4) Sieve	2.60 (kg)(lbs)
(F) % Retained on 9.5 mm (3/8 in.) Sieve = D/B x 100	47.5 %
(G) % 9.5 mm (3/8 in.) to the 4.75 mm (#4) Sieve = E/B x 100	52.5 %
(H) TOTAL	100.0 %
(J) Weight of Sample Passing the 25 mm (1 in.) Sieve and Ret 9.5 mm (3/8 in.) Sieve	1508 gms
(K) Weight of Cr. Sample Passing the 25 mm (1 in.) Sieve and Ret 9.5 mm (3/8 in.) Sieve	492 gms
(L) Weight of Sample 9.5 mm (3/8 in.) to the 4.75 mm (#4) Sieve	535 gms
(M) Weight of Cr. Sample 9.5 mm (3/8 in.) to the 4.75 mm (#4) Sieve	244 gms
(N). Percent Cr. Part. In Total Sample [(K/JxF) + (M/L x G)] x [C/70]	18.8 %
Minimum % +#4 Crushed Particles Required	10.0 %

See Grading and Base Manual Fig 1M or 1 E 5-692.204

Remarks:

cc: Project File

Fig. 1M 5-692.204

5-692.210 SIEVE ANALYSIS TEST
5-692.215M SIEVE ANALYSIS PROCEDURE (Gradation)

(METRIC PROCEDURE)

A. The procedure outlined below is for field laboratory tests and is a modification of AASHTO T-27. Procedures followed in Central and District Laboratories are on file at the Minnesota Transportation Department Laboratory, Maplewood, MN.

The sieve analysis or gradation test is a method of determining the particle size distribution of grading materials and base, subbase and surfacing aggregates using sieves with square openings. The gradation test is an extremely important test because it indicates many qualities of the tested material. The test results determine the acceptability of the material on the road and may be used to help control production at the pit.

Note: Gradation Tolerances

All required laboratory gradation samples shall have a field tested companion sample. Both samples must be split from the same larger sized sample. Both gradation test samples shall be of nearly equal size. All specified sieves **except** the 75 µm (No. 200) shall correspond within **6%** of field to laboratory test results. The 75 µm (No. 200) shall correspond within **2%**. Any sieves exceeding these tolerances will require immediate action to determine the cause of the “out of tolerance” problem.

B. Necessary apparatus for the gradation test is listed below:

1. 27.2 kg capacity dairy scale with decimal graduations in tenths of a kilogram (Interpolate reading to the nearest 0.05 kg).
2. Triple beam or torsion balance with at least 2500 grams capacity, sensitive and readable to 0.1 g.
3. Box sieves ("coarse sieves") and rocker. The usual sizes are 75 mm, 50 mm, 25 mm, 19 mm, 9.5 mm, and 4.75 mm. A bottom pan is furnished with each set of sieves.
4. Standard 200 mm diameter "fine" sieves with a fitted top and a bottom pan; the common sizes are 4.75 mm, 2 mm, 425 µm, and 75 µm. Two 75 µm sieves are required; one 75 µ should be "full height".
5. Sieve brushes (used on the "fine" sieves) includes one bristle (sash brush is ideal) and one brass. (Do not use the brass brush on the 75 µm sieve.)
6. Miscellaneous bowls, pans, and pails.
7. Stove or oven for drying.
8. Sieve shaker for fine sieves.

C. Sample

Step 1. Obtain a sample of the material according to the procedure described in 5-692.100. If necessary, reduce the size of the sample according to one of the procedures described in section 5-692.100. The weight of the gradation sample depends on the amount of gravel in the sample. Consider 15 kg the minimum size sample needed for a gradation test on "gravelly" material (base, surfacing and most subbase aggregates).

Samples of finer, granular materials with small amounts (less the 10%) of gravel and no large size rock may be less than 15 kg. The recommended sample weights or minimum sample weights are approximate and NO ATTEMPT SHALL BE MADE TO OBTAIN AN EXACT, PREDETERMINED WEIGHT FOR ANY SAMPLE THAT IS TO BE SIEVED.

Step 2. Air dry the sample to reduce the amount of fines that cling to the large particles. The sample may be cautiously dried in an oven or on the stove. Do not allow any clay balls or soil lumps to bake so hard that crumbling is difficult.

D. Procedure

The gradation test is divided into two parts; coarse sieve and fine sieve. (Refer to Form 2402, Fig. 1 5- 692.215M)

1. Coarse Sieve

Step 1. Set the coarse sieves on the rocker with the pan on the bottom and the sieves arranged in order from 4.75 mm to 75 mm on top.

Step 2. Determine the tare weight of a pail and weigh the sample to the nearest 0.05 kg on the dairy scale. Most dairy scales are equipped with a tare weight dial that can be set at zero with the pail hanging empty.

Step 3. Record the weight in the "total wt. of sample" box on Form 2402.

Step 4. Pour the sample into the sieves and shake until less than 0.5% by weight passes any sieve during one minute. Do not attempt to hand fit any rocks through a sieve.

Step 5. Examine each sieve for soil lumps and clay balls. Pulverize this material so that it passes through the sieves into the bottom pan. Never discard any clay balls from the sample.

> **Note:** Frequently the sample contains many soil lumps or is wet and cannot be dried in a reasonable length of time. Under these conditions use the 9.5 mm sieve as the final sieve. Combine the portion of the sample retained on the 4.75 mm sieve with the material in the bottom pan.

Step 6. Weigh separately the portions of the sample retained on each sieve and the material contained in the bottom pan.

Step 7. Record each weight on Form 2402 in column 1. The total of these weights must be within 100 g of the "total wt. of sample". If the "check total" is not within 100 g of "total wt. of sample", repeat Steps 4, 5, 6 and 7.

Step 8. Calculate the percent of material passing each sieve. Use Form 2402 and the following formula:

% Passing any sieve =

$$\frac{\text{Total wt. of material passing sieve}}{\text{Total wt. of sample}} \times 100$$

2. Fine Sieve

Step 1. Check the zero position of the triple beam or torsion balance. The balance must be on a level, firm base to operate accurately and reliably.

Step 2. Select a representative sample of the material in the bottom pan by one of the methods described in 5-692.100. About 450 grams (air dry) of material passing the 4.75 mm sieve or 750 grams of material passing the 9.5 mm sieve is required for a reliable fine sieve test. DO NOT ATTEMPT TO OBTAIN AN EXACT PREDETERMINED WEIGHT.

> **Note:** If testing Class 7B aggregate or any materials containing salvaged bituminous – See 5-692.216 for proper washing and drying procedures.

Step 3. Dry the sample to a constant weight. Record the dry weight on line B, Form 2402. The oven temperature may not exceed 110 C. Some materials bake into hard clusters that do not break up during washing. Therefore, it is recommended that all samples be handled as described in following note.

> **Note:** A satisfactory way to prevent the minus 75 µm material from baking is to use the "matched sample" method. After completing Step 2, prepare another sample that matches the weight and moisture content of the fine sieve sample. Dry this sample and record the dry weight on line B, Fine Sieve section of Form 2402. While the matched sample is drying, wash the representative sample; do not dry it first.

Step 4. Place the fine sieve sample into a pan and add enough water to cover the material.

Step 5. Stir the sample until the fine particles are in suspension.

Step 6. Pour the dirty water onto the full height 75 µm sieve. Do not allow the sieve to overflow (tap the side of the sieve sharply a few times if the water does not flow through the sieve).

Step 7. Add more water to the sample and repeat Step 5. and Step 6. until the water looks clean as it is poured onto the 75 µm sieve.

Step 8. Rinse the material retained on the 75 µm sieve and wash it back into the pan containing the "clean" sample.

Step 9. Pour off the excess water and dry the sample.

Step 10. Allow the sample to cool, weigh it and record the weight on line C, Form 2402.

Step 11. Pour sample into the nest of fine sieves.

Step 12. Shake sample until less than 0.5% by weight passes any sieve during a minute. Using a mechanical shaker, sieving time should be at least 7 minutes. Weigh the material retained on each sieve and in the bottom pan; record the weights in column 5, Form 2402.

The check total of the individual weights, including the loss of washing, should be within 5 grams of the original dry weight (line B).

> **Note:** The maximum weight allowed on an 200 mm wide sieve is 200 grams. Any sieve with 200 grams or more is overloaded and requires additional sieving. When it appears that the gravel being tested will regularly overload a particular sieve, obtain an intermediate size sieve (2.36 mm, 850 µm, 600 µm, or 150 µm) and add it to the nest to intercept part of the material. Remember to combine the material retained on the extra sieve with material retained on the sieve below it; or, note the extra sieve on the work sheet and include the material retained on it in the calculations.

Step 13. Calculate the cumulative percent passing each sieve and round to the nearest whole percent. Follow the procedure on Form 2402 or the formula below:

% Passing any sieve =

$$\frac{\text{Total wt. of material passing sieve}}{\text{Total wt. of sample}} \times 100$$

Step 14. Multiply the percent passing each "fine" sieve by the percent passing the final coarse sieve. The fine sieve sample is a portion of the total sample; Step 14 establishes the relationship of the fine sieve sample to the total sample. See Fig. 1 5-692.215M for an example of a complete gradation test.

3. 75 µm/25 mm Ratio

To determine the percent of 75 µm material as a percent of the portion passing the 25 mm sieve for granular materials, the part passing the 25 mm and the part passing the 75 µm sieve should be determined and recorded as described above. The 75 µm/25 mm ratio is then calculated as follows:

$$75\ \mu m/25\ mm = \frac{\%\ \text{passing}\ 75\ \mu m}{\%\ \text{passing}\ 25\ mm} \times 100$$

Note: Do not alter the sample by screening the material on the 25 mm sieve before splitting, conducting the field test or sending a companion sample to the laboratory. Determine the percent passing the 25 mm and the percent passing the 75 µm and calculate the 75 µm/25 mm ratio. Report these calculations on the back of the sample card of the companion sample.

Example:

Given:

% Passing 25 mm sieve = 97.0%

% Passing 75 µm sieve = 15.3%

Calculate:

$$75\ \mu m/25\ mm\ \text{ratio} = \frac{15.3}{97.0} \times 100 = 15.8\%$$

TP-02402-03 (5/2002)

Minnesota Department of Transportation
Office of Materials and Road Research

Work Sheet for Sieve Analysis of Granular Material

See Grading & Base Manual, Fig. 1 5-692.215

S.P.: 2704-65	Date: Oct. 11, 2001	Test No. Lot 1 2 of 4
Class: 3138 - Class 5	Station: 215-698	Layer: 150 mm
Total Weight of Sample: 14.1 (kg/lbs)		Tester: Grado Basaloni

Coarse Sieves:

	(1) Indiv. Weights	(2) Sieve Size	(3) Cumulative Wts. Passing	(4) Total % Passing	Gradation Requirements
*Pass ____ Sieve, Ret. ____ Sieve					
*Pass ____ Sieve, Ret. ____ Sieve					
*Pass ____ Sieve, Ret. 25mm Sieve	0				
*Pass 25 Sieve, Ret. 19 Sieve	0.50	25	14.00	100	100
*Pass 19 Sieve, Ret. 9.5 Sieve	3.15	19	13.50	96.4	90-100
*Pass 9.5 Sieve, Ret. 4.75 Sieve	2.50	9.5	10.35	73.9	50-90
*Pass 4.75 Sieve, Ret. Bottom	7.85	4.75	7.85	56.1	35-80
Check Total -	14.00	- Shall Check Total Wt. Within 0.1 kg (0.2lbs)			

*Enter necessary sieve sizes for class of material to be tested.
Column (1) Enter weights of material between each set of sieves individually.
Column (2) Enter the passing sieves size.
Column (3) Add column (1) from the bottom up to get cumulative weights passing each sieve.
Column (4) Divide column (3) by check total of sample to get total % passing.

Fine Sieves:

(A) Take two samples identical in condition and damp weight from "passing 4.75 mm material".
(B) Dry on sample and record weight. 510.8
(C) Wash and dry other sample and record weight. 473.4
(D) Loss in washing (B-C) (Enter Below) 37.4

	(5) Indiv. Weights	(6) Sieve Size	(7) Cumulative Wts. Passing	(8) Cum. % Passing	(9) % Passing of Total Pass.	Gradation Requirements
*Pass ____ Sieve, Ret. ____ Sieve						
*Pass ____ Sieve, Ret. ____ Sieve						
*Pass ____ Sieve, Ret. ____ Sieve						
*Pass 4.75 Sieve, Ret. 2mm Sieve	82.2	4.75	510.0	100	56.1	
*Pass 2 Sieve, Ret. 425 μm Sieve	183.8	2	427.8	83.9	47.1	20-65
*Pass 425 Sieve, Ret. 150 μm Sieve	158.0	425	244.0	47.8	26.8	10-35
*Pass 150 Sieve, Ret. 75 μm Sieve	42.0	150	86.0			
*Pass 75 μm Sieve, Ret. Bottom	6.6	75	44.0	8.6	4.8	3-10
Loss by washing-	37.4					
Check Total -	510.0	- Shall Check total Wt. Within 5 grams				
Percent Passing 75 μm (#200) Sieve Divided by Percent Passing 25 mm (1 in.) Sieve (if specified)						—

Column (5) Enter weights of material between each set of sieves and loss by washing (DO NOT OVERLOAD SIEVES)
Column (6) Enter the passing sieve size.
Column (7) Add column (5) from bottom up to get cumulative weights passing each sieve. Be sure to add loss by washing to weight of material of material passing 75 μm (#200) sieve to get first entry at bottom of column (7).
Column (8) Divide column (7) by check total dry weight of fine sample (Column 5) to get cumulative % passing.
Column (9) Multiply column (8) by % passing final sieve from column (4) to get "Percent Passing" based on total sample.

CC: Project File

Figure 1 5-692.215M

5-692.215E SIEVE ANALYSIS PROCEDURE (Gradation)

(ENGLISH PROCEDURE)

A. The procedure outlined below is for field laboratory tests and is a modification of AASHTO T-27. Procedures followed in Central and District Laboratories are on file at the Minnesota Transportation Department Laboratory, Maplewood, MN.

The sieve analysis or gradation test is a method of determining the particle size distribution of grading materials and base, subbase and surfacing aggregates using sieves with square openings. The gradation test is an extremely important test because it indicates many qualities of the tested material. The test results determine the acceptability of the material on the road and may be used to help control production at the pit.

Note: Gradation Tolerances
All required laboratory gradation sampels shall have a field tested companion sample. Both samples must be split from the same larger sized sample. Both gradation test samples shall be of nearly equal size. All specified sieves **<u>except</u>** the 75 µm (No. 200) shall correspond within **6%** of field to laboratory test results. The 75 µm (No. 200) shall correspond within **2%**. Any sieves exceeding these tolerances will require immediate action to determine the cause of the “out of tolerance” problem.

B. Necessary apparatus for the gradation test is listed below:

1. 60 lb. capacity dairy scale with decimal graduations in tenths of a pound.
2. Triple beam or torsion balance with at least 2500 grams capacity, sensitive and readable to 0.1 g.
3. Box sieves ("coarse sieves") and rocker. The usual sizes are 3”, 2”, 1”, 3/4” 3/8”, and No. 4. A bottom pan is furnished with each set of sieves.
4. Standard 8” diameter "fine" sieves with a fitted top and a bottom pan; the common sizes are No. 4, No. 10, No. 40, and No. 200. Two No. 200 sieves are required; one No. 200 should be "full height".
5. Sieve brushes (used on the "fine" sieves) includes one bristle (sash brush is ideal) and one brass. (Do not use the brass brush on the No. 200 sieve.)
6. Miscellaneous bowls, pans, and pails.
7. Stove or oven for drying.
8. Sieve shaker for fine sieves.

C. Sample

Step 1. Obtain a sample of the material according to the procedure described in 5-692.100. If necessary, reduce the size of the sample according to one of the procedures described in 5-692.100. The weight of the gradation sample depends on the amount of gravel in the sample. Consider 25 lbs. the minimum size sample needed for a gradation test on "gravelly" material (base, surfacing and most subbase aggregates).

Samples of finer, granular materials with small amounts (less the 10%) of gravel and no large size rock may be less than 25 lbs. The recommended sample weights or minimum sample weights are approximate and NO ATTEMPT SHALL BE MADE TO OBTAIN AN EXACT, PREDETERMINED WEIGHT FOR ANY SAMPLE THAT IS TO BE SIEVED.

Step 2. Air dry the sample to reduce the amount of fines that cling to the large particles. The sample may be cautiously dried in an oven or on the stove. Do not allow any clay balls or soil lumps to bake so hard that crumbling is difficult.

D. Procedure

The gradation test is divided into two parts; coarse sieve and fine sieve. (Refer to Form 2402, Fig. 1 5- 692.215E)

1. Coarse Sieve

Step 1. Set the coarse sieves on the rocker with the pan on the bottom and the sieves arranged in order from No. 4 to 3” on top.

Step 2. Determine the tare weight of a pail and weigh the sample to the nearest 0.1 lb. on the dairy scale. Most dairy scales are equipped with a tare weight dial that can be set at zero with the pail hanging empty.

Step 3. Record the weight in the "total wt. of sample" box on Form 2402.

Step 4. Pour the sample into the sieves and shake until less than 0.5% by weight passes any sieve during one minute. Do not attempt to hand fit any rocks through a sieve.

Step 5. Examine each sieve for soil lumps and clay balls. Pulverize this material so that it passes through the sieves into the bottom pan. Never discard any clay balls from the sample.

> **Note:** Frequently the sample contains many soil lumps or is wet and cannot be dried in a reasonable length of time. Under these conditions use the 3/8” sieve as the final sieve. Combine the portion of the sample retained on the No. 4 sieve with the material in the bottom pan.

Step 6. Weigh separately the portions of the sample retained on each sieve and the material contained in the bottom pan.

Step 7. Record each weight on Form 2402 in column 1. The total of these weights must be within 0.2 lbs. of the "total wt. of sample". If the "check total" is not within 0.2 lbs. of "total wt. of sample", repeat Steps 4, 5, 6, and 7.

Step 8. Calculate the percent of material passing each sieve. Use Form 2402 and the following formula:

% Passing any sieve =

$$\frac{\text{Total wt. of material passing sieve}}{\text{Total wt. of sample}} \times 100$$

3. Fine Sieve

Step 1. Check the zero position of the triple beam or torsion balance. The balance must be on a level, firm base to operate accurately and reliably.

Step 2. Select a representative sample of the material in the bottom pan by one of the methods described in 5-692.100. About 450 grams (air dry) of material passing the No. 4 sieve or 750 grams of material passing the 3/8” sieve is required for a reliable fine sieve test. DO NOT ATTEMPT TO OBTAIN AN EXACT PREDETERMINED WEIGHT.

> **Note:** If testing Class 7B aggregate or any materials containing salvaged bituminous – See 5-692.216 for proper washing and drying procedures.

Step 3. Dry the sample to a constant weight. Record the dry weight on line B, Form 2402. The oven temperature may not exceed 230 F. Some materials bake into hard clusters that do not break up during washing. Therefore, it is recommended that all samples be handled as described in following note.

> **Note:** A satisfactory way to prevent the minus No. 200 material from baking is to use the "matched sample" method. After completing Step 2, prepare another sample that matches the weight and moisture content of the fine sieve sample. Dry this sample and record the dry weight on line B, Fine Sieve section of Form 2402. While the matched sample is drying, wash the representative sample; do not dry it first.

Step 4. Place the fine sieve sample into a pan and add enough water to cover the material.

Step 5. Stir the sample until the fine particles are in suspension.

Step 6. Pour the dirty water onto the full height No. 200 sieve. Do not allow the sieve to overflow (tap the side of the sieve sharply a few times if the water does not flow through the sieve).

Step 7. Add more water to the sample and repeat Step 5 and Step 6 until the water looks clean as it is poured onto the No. 200 sieve.

Step 8. Rinse the material retained on the No. 200 sieve and wash it back into the pan containing the "clean" sample.

Step 9. Pour off the excess water and dry the sample.

Step 10. Allow the sample to cool, weigh it and record the weight on line C, Form 2402.

Step 11. Pour sample into the nest of fine sieves.

Step 12. Shake sample until less than 0.5% by weight passes any sieve during a minute. Using a mechanical shaker, sieving time should be at least 7 minutes. Weigh the material retained on each sieve and in the bottom pan; record the weights in column 5, Form 2402.

The check total of the individual weights, including the loss of washing, should be within 5 grams of the original dry weight (line B).

> **Note:** The maximum weight allowed on an 8" wide sieve is 200 grams. Any sieve with 200 grams or more is overloaded and requires additional sieving. When it appears that the gravel being tested will regularly overload a particular sieve, obtain an intermediate size sieve (No. 8, No. 20, No. 30, or No. 100) and add it to the nest to intercept part of the material. Remember to combine the material retained on the extra sieve with material retained on the sieve below it; or, note the extra sieve on the work sheet and include the material retained on it in the calculations.

Step 13. Calculate the cumulative percent passing each sieve and round to the nearest whole percent. Follow the procedure on Form 2402 or the formula below:

$$\text{\% Passing any sieve} = \frac{\text{Total wt. of material passing sieve}}{\text{Total wt. of sample}} \times 100$$

Step 14. Multiply the percent passing each "fine" sieve by the percent passing the final coarse sieve. The fine sieve sample is a portion of the total sample; Step. 14 establishes the relationship of the fine sieve sample to the total sample. See Fig. 1 5-692.215E for an example of a complete gradation test.

3. No. 200/1” Ratio

To determine the percent of No. 200 material as a percent of the portion passing the 1” sieve for granular materials, the part passing the 1” and the part passing the No. 200 sieve should be determined and recorded as described above. The No. 200/1” ratio is then calculated as follows:

$$\text{No. 200/1"} = \frac{\text{\% passing No. 200}}{\text{\% passing 1"}} \times 100$$

Note: Do not alter the sample by screening the material on the 1” sieve before splitting, conducting the field test or sending a companion sample to the laboratory. Determine the percent passing the 1” and the percent passing the No. 200 and calculate the No. 200/1” ratio. Report these calculations on the back of the sample card of the companion sample.

Example:
Given:
% Passing 1” sieve = 97.0%
% Passing No. 200 sieve = 15.3%
Calculate:

$$\text{No. 200/1" ratio} = \frac{15.3}{97.0} \times 100 = 15.8\%$$

TP-02402-03 (5/200?

Minnesota Department of Transportation
Office of Materials and Road Research

Work Sheet for Sieve Analysis of Granular Material

See Grading & Base Manual, Fig. 1 5-692.215

S.P.: 4247-10	Date: Oct. 1, 2001	Test No. Lot 4 3 of 4
Class: 3138-7C for 5	Station: 15+50	Layer: 6"
Total Weight of Sample: 31.0 kg (lbs)		Tester: Van Davson

Coarse Sieves:

	(1) Indiv. Weights	(2) Sieve Size	(3) Cumulative Wts. Passing	(4) Total % Passing	Gradation Requirements
*Pass ___ Sieve, Ret. ___ Sieve					
*Pass ___ Sieve, Ret. ___ Sieve					
*Pass ___ Sieve, Ret. 1" Sieve	.				
*Pass 1 Sieve, Ret. 3/4 Sieve	1.0	1"	30.9	100	100
*Pass 3/4 Sieve, Ret. 3/8 Sieve	7.1	3/4	29.9	96.8	90-100
*Pass 3/8 Sieve, Ret. #4 Sieve	5.4	3/8	22.8	73.8	50-90
*Pass #4 Sieve, Ret. Bottom	17.4	#4	17.4	56.3	35-80
Check Total -	30.9	- Shall Check Total Wt. Within 0.1 kg (0.2lbs)			

*Enter necessary sieve sizes for class of material to be tested.
Column (1) Enter weights of material between each set of sieves individually.
Column (2) Enter the passing sieves size.
Column (3) Add column (1) from the bottom up to get cumulative weights passing each sieve.
Column (4) Divide column (3) by check total of sample to get total % passing.

Fine Sieves:

(A) Take two samples identical in condition and damp weight from "passing #4 material".
(B) Dry on sample and record weight. 510.8
(C) Wash and dry other sample and record weight. 473.4
(D) Loss in washing (B-C) (Enter Below) 37.4

	(5) Indiv. Weights	(6) Sieve Size	(7) Cumulative Wts. Passing	(8) Cum. % Passing	(9) % Passing of Total Pass.	Gradation Requirements
*Pass ___ Sieve, Ret. ___ Sieve						
*Pass ___ Sieve, Ret. ___ Sieve						
*Pass ___ Sieve, Ret. ___ Sieve						
*Pass 4 Sieve, Ret. 10 Sieve	82.2	4	510.0	100	56.3	
*Pass 10 Sieve, Ret. 40 Sieve	183.8	10	427.8	83.9	47.2	20-65
*Pass 40 Sieve, Ret. 100 Sieve	158.0	40	244.0	47.8	26.9	10-35
*Pass 100 Sieve, Ret. 200 Sieve	42.0	100	86.0	—	—	
*Pass 200 Sieve, Ret. Bottom	6.6	200	44.0	8.6	4.8	3-10
Loss by washing-	37.4					
Check Total -	510.0	- Shall Check total Wt. Within 5 grams				
Percent Passing 75 µm (#200) Sieve Divided by Percent Passing 25 mm (1 in.) Sieve (if specified)						—

Column (5) Enter weights of material between each set of sieves and loss by washing (DO NOT OVERLOAD SIEVES)
Column (6) Enter the passing sieve size.
Column (7) Add column (5) from bottom up to get cumulative weights passing each sieve. Be sure to add loss by washing to weight of material of material passing 75 µm (#200) sieve to get first entry at bottom of column (7).
Column (8) Divide column (7) by check total dry weight of fine sample (Column 5) to get cumulative % passing.
Column (9) Multiply column (8) by % passing final sieve from column (4) to get "Percent Passing" based on total sample.

CC: Project File

Figure 1 5-692.215E

5-692.216 Procedures for Washing and Drying Gradation Samples Containing Salvaged Bituminous

A. Dry the sample to a constant weight at a temperature not to exceed 60ºC (140ºF) or use the “matched sample” method described in 5-692.215.D.2 Step 3 – **Note** M or E.

B. If necessary, soak the sample in suitable detergents or dispersants for a time period and at concentration levels sufficient to remove the oly film from the virgin fraction of the sample.

> **Note:** The concentration of the detergent/dispersant shall not be so harsh so as to break down the film of asphalt on the particles of salvaged asphalt pavement.

C. Wash the sample through the 75 µm (No. 200) sieve as above or in accordance with 5-692.215M or E.

D. Dry the sample in accordance with the following methods:

1. In an oven at temperature not to exceed 60ºC (140ºF) overnight.

2. Over a hot plate or stove-top electric burner using a sand bath having a minimum depth of 37.5mm (1.5”). Control the temperature of the sand to prevent the drying sample from exceeding 60ºC (140ºF). Stir the sample occasionally in the early drying stages and continuously as the sample approaches a constant weight.

E. Cool and sieve the sample in accordance with the established procedures in 5-692.215M or E.

Note: Moisture-Density Test (Proctor) Tolerances
All required laboratory Proctor samples shall have a field tested companion sample. Both samples must be split from the same larger sized sample. The field and laboratory Proctor test samples shall be of nearly equal size after spliting. Both **maximum density** tests shall correspond within **50kg/m3 (3 lbs./cu.ft.)** from field to laboratory test and both **optimum moisture** tests shall correspond within **2%**. Any testing exceeding these tolerances will require immediate action to determine the cause of the “out of tolerance” problem.

5-692.222M MOISTURE-DENSITY TEST METHOD (PROCTOR) (METRIC)

Note: Moisture-Density Test (Proctor) Tolerances
All required laboratory Proctor samples shall have a field tested companion sample. Both samples must be split from the same larger sized sample. The field and laboratory Proctor test samples shall be of nearly equal size after spliting. Both **maximum density** tests shall correspond within **50kg/m3 (3 lbs./cu.ft.)** from field to laboratory test and both **optimum moisture** tests shall correspond within **2%**. Any testing exceeding these tolerances will require immediate action to determine the cause of the "out of tolerance" problem.

A. This Moisture-Density Test (Proctor) is a method of determining the relationship between the moisture content and the density of the grading soil, base or subbase aggregate when compacted by following a standard procedure. This method is consistent with AASHTO T-99, Method C.

The Maximum Density is the highest dry density that can be obtained by varying the moisture contents and compacting the material by following a standard procedure. The Optimum Moisture content is the moisture content (expressed as percent of dry weight) of the soil, base or subbase aggregate at the Maximum Density. When compaction is controlled by the Specified Density Method, the moisture content of the soil or aggregate being placed is compared to the Optimum Moisture content and the density of the in-place compacted material is compared to the Maximum Density to determine compliance with the specification requirements. The moisture content of the soil or aggregate compared to the Optimum Moisture content of the same soil indicates the amount of compactive effort needed to achieve the Specified Density. A soil with a moisture content lower than the Optimum Moisture requires more compactive effort than the same soil with a moisture content near "optimum". Soils with moisture contents higher than "optimum" tend to be unstable and may be impossible to compact.

When the Quality Compaction Method is required, knowledge of the optimum moisture and maximum density for the material helps the inspector determine the moisture necessary for proper compaction.

B. **Apparatus (Metric)**

1. Proctor mold - A cylindrical metal mold having a capacity of 1/1060th cu. meter with an internal diameter of 101.6 ± 0.406 mm and a height of 116.43 ± 0.1270 mm. The mold shall have a detachable collar assembly and base plate. (Figure 1 5- 692.222M).
2. Rammer - Metal rammer having a flat circular face of 50.8 ± 0.127 mm diameter and weighing 2.495 ± 0.009 kg. The rammer shall be equipped with a guide-sleeve to control the height of drop to a free fall of 304.8 ± 1.524 mm above the soil. (Figure 2).
3. Platform scale - The platform scale shall have a minimum capacity of 14 kg; it shall be sensitive to one gram and the minor graduations on the indicator shall be one gram.

4. Balance - The balance shall have a minimum capacity of 2500 g; it shall be sensitive to 0.1 g and the minor gradations on the indicator shall be for 0.1 g.
5. Drying oven or stove.
6. Mixing tools. (Figure 3).
7. Spatula and butcher knife. (Figure 3).

8. Box sieves, 50 mm, 19 mm, 9.5 mm and 4.75 mm with bottom pan.
9. Concrete compaction base. A block of concrete weighing not less than 50 kg supported on a stable foundation; a sound concrete floor or other solid surface found in concrete box culverts, bridges and pavement. See Figure 4 for typical test equipment set-up.

C. Sample Preparation

Step 1. Obtain a sample of the soil or aggregate according to the procedures described in 5-692.221.

Step 2. If the soil sample is damp, dry it until it becomes friable under a trowel. The sample may be air dried or dried in the oven or on the stove such that the temperature does not exceed 60ºC.

Step 3. Sieve an adequate quantity of the sample over the 50 mm, 19 mm and 4.75 mm on bottom pan. Break up all soil lumps to pass the sieves.

Step 4. Discard the stones retained on the 50 mm sieve.

Step 5. Weigh the stones that pass the 50 mm sieve and are retained on the 19 mm sieve.

Step 6. Discard the stones retained on the 19 mm sieve and replace them with an equal weight of stones passing the 19 mm sieve and retained on the 4.75 mm sieve.

> **Note:** The replacement material may be obtained from the remaining portion of the sample, a companion sample or completed gradation sample.

Step 7. If the sample contains soil lumps and clay balls, pulverize them so they pass through the 4.75 mm sieve.

> **Note:** When a large portion of the sample consists of lumps, use a 9.5 mm sieve as well as the 4.75 mm.

Step 8. Recombine any stones retained on the 4.75 mm (and 9.5 mm) sieve(s) with the pulverized material in the pan.

Step 9. Select about 5 kg or more of the prepared sample using a procedure described in 5-692.212, .213 or .214.

D. **PROCTOR METHOD** (Multi-Point)

This test consists of compacting a portion of a soil sample in a mold at different moisture contents ranging from dry to wet. **At least 4 samples** will be run. The samples will differ in moisture content by one to two percent with the driest sample being about four percentage points below optimum moisture. This would result in two of the samples being below optimum, one near optimum and one over optimum. A valid test will have 2 points below optimum.

1. **Standard Method**

Step 1. Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately 4 percentage points below optimum moisture content.

> **Note:** To estimate the starting point for granular soils (less than 20% passing the 75 µm sieve), moisten and mix the soil until it can be squeezed into a ball or "cast". The cast should crumble easily when touched. Soils with more than 20% passing the 75 µm sieve usually have higher optimum moisture than granular soils and the cast is less easily crumbled at the starting point.

Step 2. Determine the weight of the mold and base plate. Record the weight as "B-Wt. Mold". See Figure 5, 5-692.222. DO NOT INCLUDE THE WEIGHT OF THE COLLAR.

Step 3. Place the assembled mold, including collar, on the concrete compaction base.

Step 4. Place enough of the sample into the mold for one layer.

> **Note:** The mold is filled with three equal layers of compacted material. After compaction, the top layer should be about 15 mm over the top of the mold when the collar is removed.

Step 5. Compact the loose material by 25 uniformly distributed blows from the rammer dropping freely from a height of 305 mm above the soil.

Step 6. Repeat Steps 4 and 5 until the three layers are placed and compacted.

Step 7. Remove the collar and carefully trim the compacted soil with the knife until it is even with the top of the mold (check with the spatula). Remove any stones dislodged by trimming and fill the holes by carefully pressing finer material into place. Trim around any stones that are at least half buried and solidly seated.

Step 8. Clean all the loose material from the mold and base plate and weigh it on the platform scale to the nearest gram. Record the weight as "A-Wt. Wet Soil + Mold".

Step 9. Remove the mold from the base plate and loosen the locking devices so that the compacted material can be removed from the mold.

Step 10. Quarter the compacted material by slicing twice vertically through the compacted soil. Select one of the quarters and weigh immediately. Conduct the moisture determination according to the procedure in 5-692.245.

Note: A representative sample must consist of nearly equal portions of material from all three layers. When the “Speedy” method is used, take the sample the same way as the burner dry method and use a representative portion for the moisture determination.

Step 11. Thoroughly break up any remaining portion of the molded specimen and add it to the sample being tested.

Step 12. Add enough water to increase the moisture content about two percentage points.

Note: 90 cc, mls or grams of water will increase the moisture content of 4.4 kg of material about two percentage points. Additional water may be needed to replace moisture lost by evaporation during mixing.

Note: In each repetition the material shall be thoroughly mixed before compaction to assure uniform dispersion of the moisture throughout the sample.

Step 13. Repeat Steps 4 thru 12 until the “Wt. Wet Soil + Mold” determined in Step 8 either decreases or fails to increase. At this point the compacted material should be soft and spongy; granular material may not be very spongy but will be extremely wet. The spongy condition indicates that the moisture content of the sample exceeds optimum.

2. **Alternate Method**

The above procedure is satisfactory in most cases. However, if the soil is fine grained, cohesive and difficult to break up and mix with water or if the material is fragile and will reduce significantly in grain size due to repeated compaction, use the following procedure:

Step 1. Prepare the sample as outlined in Paragraph C, Steps 1 thru 8.

Step 2. Select about 11 kg of the prepared material using a procedure described in 5-692.212, .213 or .214.

Step 3. Moisten or dry the sample to about four percentage points below the estimated optimum moisture. See “Note” Step 1 in Paragraph D above.

Step 4. Divide the sample into four or five portions of about 2.2 kg each.

Step 5. Place one portion into a water tight container, cover, set aside, and mark as “point No. 1".

Step 6. Add enough water to one of the remaining portions to increase the moisture content about two percentage points. (45 mls., cc or grams of water added to 2.2 kg of material will increase the moisture content 2.0 percent.) Place this portion in a container and mark as “point No. 2".

Step 7. Continue this process with the remaining two or three portions and increase the amount of water each time until there is a series of points at about 2, 4, 6, and 8 percentage points over “point No. 1". At least one ”point" should exceed the estimated optimum moisture.

> Example: A clay loam soil is to be tested. It is coming from the cut of about 20% moisture. The estimated optimum moisture is about 18%. It is necessary to dry the soil to about 8% moisture before it can be pulverized. After the soil is pulverized, the inspector mixes 11 kg of soils with enough water (450 cc) to bring it to about 12% moisture. The inspector divides the sample into five samples. weighing about 2.2 kg each, and places them into concrete cylinder molds labeled “point No. 1", ”point No. 2", etc. “Point No. 1" is covered and set aside. He adds 45 cc of water to No. 2, 90 cc to No. 3, 135 cc to No. 4 and 180 cc to No. 5, mixes, covers and sets them aside.

Step 8. Allow the covered material to “soak” in the molds overnight (twelve hours minimum) to permit the moisture to disperse through the soil.

Step 9. Compact each portion following Step 2 through 10 of the Standard Method.

> **Note:** If heavy clay or organic soils exhibiting flat enlongated curves are encountered, the water content increments may be increased to a maximum of 4 percent.

E. Calculations (Refer to Figure 5 5-692.222M)

1. Wet Density

A = Wt. Wet Soil + Mold kg
B = Wt. Mold kg
C = Wt. Wet Soil (A-B)
D = Wet Density, kg/m^3 (C x 1059.43)

Note: 1059.43 = Number of “Mold Castings” per cu. meter (m^3).

Example:

A = 7.46 kg
B = 5.63 kg
C = 7.46 - 5.63 = 1.83 kg
D = 1.83 x 1059.43 = 1939 kg/m^3

2. Percent Moisture Burner Method

E = Wt. Wet Soil + Pan grams
F = Wt. Dry Soil + Pan grams
G = Wt. Moisture (E-F)
H = Wt. pan, grams
I = Wt. Dry Soil (F-H)
J = % Moisture, Wet Wt. - [G/(E-H)] x 100
K = % Moisture, Dry Wt. = (G/I) x 100

Example:
E = 385.6 grams
F = 350.2 grams
G = 385.6 - 350.2 = 35.4 grams
H = 93.8 grams
I = 350.2 - 93.8 = 256.4 grams
K = (35.4/256.4) x 100 = 13.8%

3. Speedy Method

If the % Moisture, Wet Wt. (J) is recorded, determine and record the % Moisture, Dry Wt. (k) by using Table A 5-692.250 or the following formula:

$$K = \frac{J}{1.0 - \left(\frac{J}{100}\right)}$$

Example:
J = 12.3 (gauge reading from Speedy Moisture Meter)

$$K = \frac{12.3}{1.0 - \left(\frac{12.3}{100}\right)} = 14.0\%$$

4. Dry Density

L = Dry Density, kg/m^3 =
[D/(100 + K)] x 100
Example: L= [1939/(100 + 13.8)] x 100 = 1702

F. The Maximum Density and Optimum Moisture Content.

The Maximum density and optimum moisture are determined by graphing the information obtained by compacting the samples at various moisture contents. Each moisture content relates to a wet density and to a dry density.

Example: (From Fig. 5 5-692.222M)

	Point				
	No. 1	No. 2	No. 3	No.. 4	No. 5
D. Wet Density	1939	1992	2034	2034	1992
K. % Moisture	13.8	15.0	17.0	18.2	19.7
L. Dry Density	1702	1732	1738	1721	1664

Important Notice: The drawing of the "wet" curve is not required if the laboratory tester has compacted four adequate points as described previously. But, if the "wet" curve is not drawn, the "dry" curve must be computer generated. All discrepancies between companion samples shall be resolved by plotting the "wet" curve by hand and interpolating the "dry" curve points as shown below.

Step 1. Plot the wet densities against the moisture contents on a Form 2430. (Figure 6).

Step 2. Draw a smooth curve thru the plotted points. (Figure 7). This is the "wet curve".

Step 3. Plot the dry densities against the moisture contents. (Figure 8). Additional "dry points" may be interpolated from the "wet curve".

Example: In Figure 8, Points P and PP are used to establish points P_1 and PP_1 on the "dry curve".

D. (Wet Density) for Point P = 2003 kg/m^3
K. (Moisture) for Point P and P_1 = 15.4%.
L. (Dry Density) for point P_1 = [2003/(100 + 15.4)] x 100 =1736 kg/m^3
and
D. (Wet Density) for Point PP = 2022 kg/m^3
K. (Moisture) for Point PP and PP_1 = 16.2%.
L. (Dry Density) for point PP_1 = [2022/(100 + 16.2)] x 100 =1740 kg/m^3

Step 4. Draw a smooth curve thru the plotted points. (Figure 9). This is the "dry curve".

Step 5. Read the maximum density and optimum moisture from the peak of the "dry curve". (Figure 9). Maximum Density = 1740 kg/m^3; Optimum Moisture = 16.2%.

G. PROCTOR (One-Point Method)
Use this method for determining the standard maximum density and optimum moisture on grading soils only and never on base or subbase aggregates. Also, this method is for field testing only. Never use the one-point Proctor method in lieu of a "multi-point" moisture-density test on a Project's major grading soil. Use the one-point method to

analyze subtle changes occurring between major grading soils. Slight changes in color, texture, structure, etc. (See 5-692.600) may indicate these changes. Also, use one-point Proctors to verify changes in maximum density and optimum moisture indicated by relative densities (sand cone tests) failing to meet specified density requirements even though operations have not changed and previous tests have passed. Relative density tests exceeding 106 percent suggest zero air voids and indicate a possible change in maximum density. Run a one-point Proctor to confirm the suspected change. Use the "multi-point" moisture density test for the material closest to the soil with this subtle change to check the testing accuracy of the one-point Proctor. A reasonable variation should not exceed plus or minus 50 kilograms per cubic meter. If the variation exceeds 50 kilograms, run another "multi-point" Proctor.

Step 1. Obtain a representative sample of soil from the fill area. (See 5-692.221).

> **Note:** 1.5 to 3 kg of “minus 4.75 mm” material is usually enough to complete the test; however, it may be necessary to take much more than 3 kg to have a ”representative" sample.

Step 2. Sieve the sample through a 4.75 mm sieve. If it is necessary to dry the sample, do not allow it to become “oven” or “stove” dry. Be sure to pulverize all clay lumps.

Step 3. Weigh the stones retained on the 4.75 mm sieve, record the weight and <u>discard</u> the stones.

Step 4. Weigh the portion of the sample passing the 4.75 mm sieve. Record the weight.

Step 5. Calculate the percent of the sample retained on the 4.75 mm sieve as follows:

$$C = \frac{A}{A + B} \times 100$$

C = % retained on the 4.75 mm sieve.
A = Wt. of plus 4.75 mm material (Step 3)
B = Wt. of minus 4.75 mm material (Step 4)

Example:
A = 997.9 g
B = 4422.5 g

$$C = \frac{997.9}{997.9 + 4422.5} \times 100$$

$$C = 18\%$$

Step 6. Reduce the size of the minus 4.75 mm portion of the sample to about 3 kg by quartering or splitting (5-692.212 or 5-692.214).

Step 7. Add water to the reduced sample and mix thoroughly until the material is damp enough to compact well; do not add so much water that the soil becomes "spongy" when compacted.

Step 8. Determine the weight of the mold and base plate. Record the weight.

Step 9. Place the assembled mold, including the collar, on the compaction base.

Step 10. Scoop enough material into the mold for 1 layer.

> **Note:** The mold is filled with 3 equal layers of compacted material; the top layer, after compaction, should be about 15 mm over the top of the mold when the collar is removed.

Step 11. Compact the loose material with 25 evenly distributed blows with the rammer dropped from 300 mm.

Step 12. Repeat Steps 10 and 11 until 3 layers are inplace.

Step 13. Remove the collar and trim the compacted material with a knife until even with the top of the mold. (Check with a spatula.)

Step 14. Brush all loose material from the mold and base plate and weigh the mold to the nearest gram on the platform scale. Record the weight.

Step 15. Calculate the wet weight per cubic meter of the compacted material.

$F = 1059.43\ (D\text{-}E)$
F = Wet wt. per cu. meter
D = Weight of wet soil and mold (Step 14).
E = Weight of the mold (Step 8).

Example:

D = 7.58 kg, E = 5.67 kg
$F = 1059.43\ (7.58 - 5.67)$
$F = 2024\ kg/m^3$

Step 16. Remove the mold from the base plate and loosen the locking devices so the compacted material can be removed from the mold.

Step 17. Select a representative sample for a moisture test. Conduct the test according to the procedures in 5-692.245. Record the results.

Step 18. Using the Typical Moisture Density Curves (Fig. 10 5-692.222M) determine the optimum moisture and maximum density of the minus 4.75 mm material.

Example:

Given: Wet wt. per m^3 = 2024 kg (Step 15)
Moisture = 14.1% (Step 17).

Follow the <u>horizontal</u> line representing the wet weight (2024 kg) across the chart until it intersects the <u>vertical</u> line representing the moisture (14.1). The Typical Curve lying nearest the point of intersection (“M”) represents the maximum density and optimum moisture of the minus 4.75 mm material. For curve M, the maximum dry density is 1794 kg/m^3 and the optimum moisture is 15.8%.

Step 19. If the amount of plus 4.75 mm material determined by Step 5 <u>exceeds</u> 5%, the maximum density and optimum moisture of the minus 4.75 mm material must be adjusted to account for the plus 4.75 mm portion of the representative sample. The density is adjusted by the following calculation:

$H = (1.0-C)G + 2384(C)$
H = Maximum Density of the total sample.
G = Maximum Density of the minus No. 4.75 mm portion.
C = % retained on the 4.75 mm sieve, expressed as a decimal.

Example:

Given:
$G = 1794; C = 18\% = 0.18$
$H = (1.0-0.18)\ 1794 + 2384\ (0.18)$
$H = 1900\ kg/m^3$

The Optimum Moisture is adjusted by the following calculation:

$J = 2(C) + (1.0-C)I$
J = Optimum Moisture of the total sample.
I = Optimum Moisture of the minus 4.75 mm portion.
C = % retained on the 4.75 mm sieve, expressed as a decimal.

Example:

Given:
$I = 15.8\%; C = 18\% = 0.18$
$J = 2(0.18) + (1-0.18)15.8$
$J = 13.3$

The Standard Maximum Density and Optimum Moisture for the sample selected in Step. 1 is 1900 kg/m^3 and 13.3%.

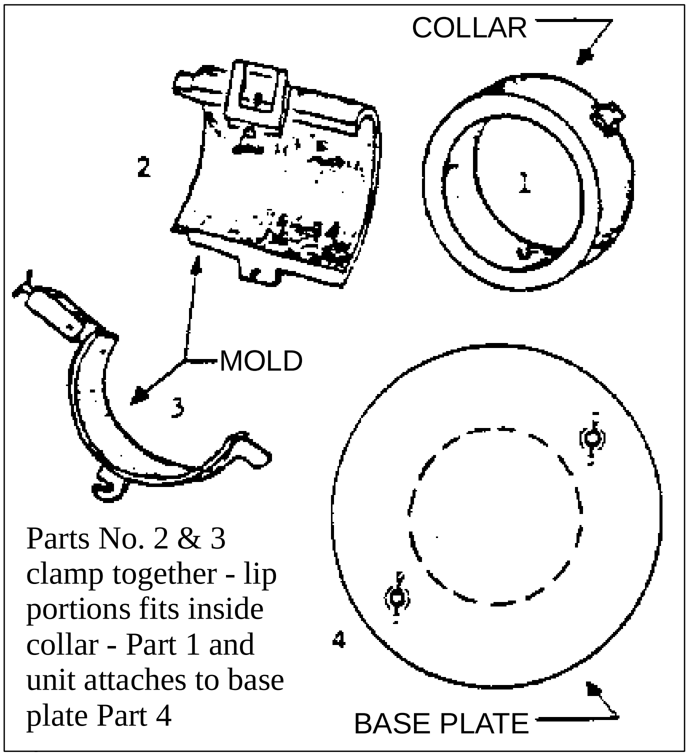


Figure 1 - Mositure-Density Test Mold

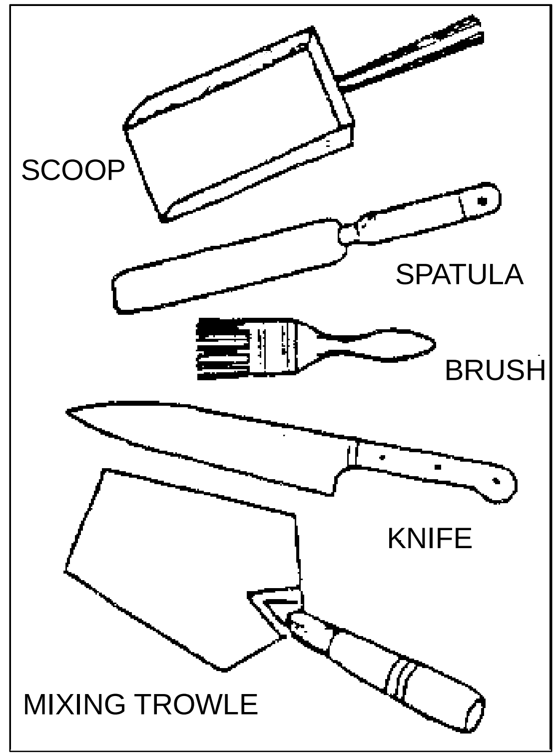


Figure 3 - Typical Tools

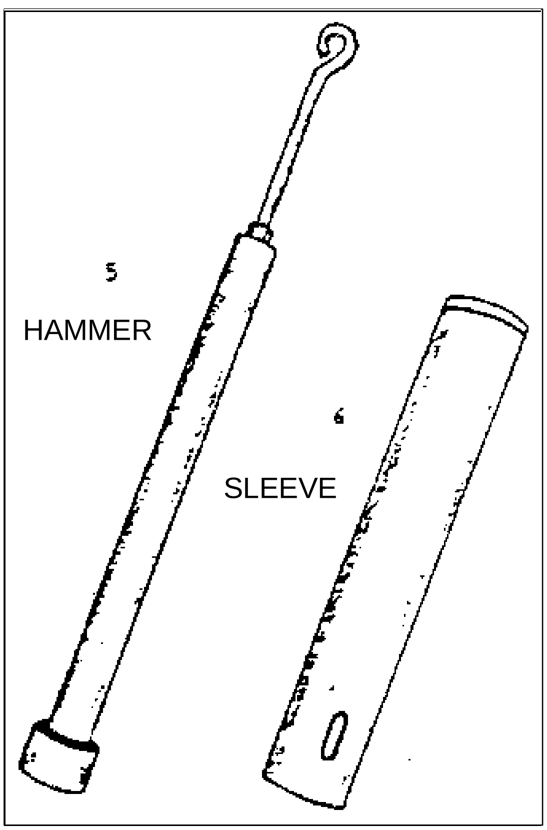


Figure 2 - Rammer

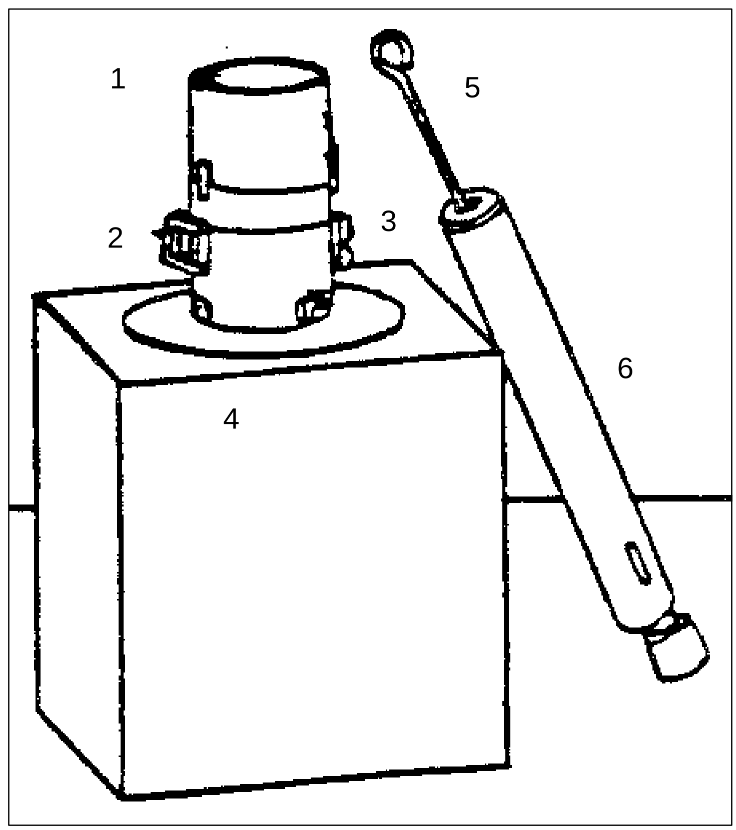


Figure 4 - Typical Set-up for Moisture-Density Test

Figures 1-4 5-692.222M

TP-24587-01 (3/13/02)

Minnesota Department of Transportation

Office of Materials and Road Research

Calculation for Moisture - Density Relationships in Subgrade Soils and Aggregate Base and Shoulders

Units Metric

Sample No: 17	Curve No: 6	Date: 8-12-01
		S. P. No: 1980-101

Optimum Moisture (M_t) 16.2 %

Maximum Density (Dt) 1740 kg/m³ (lb/ft³)

A - Wt. Wet Soil + Mold	7.46	7.51	7.55	7.55	7.51
B -Wt. Mold	5.63	5.63	5.63	5.63	5.63
C - Wt. Wet Soil	1.83	1.88	1.92	1.92	1.88
D - Wet Density kg/m³ (lb/ft³)	1939	1992	2034	2034	1992
- Burner Method -					
E - Wt. Wet Soil + Pan	385.6	408.1	378.1	383.8	381.2
F - Wt. Dry Soil + Pan	350.2	367.1	336.8	339.2	333.8
G - Wt Moisture	35.4	41.0	41.3	44.6	47.4
H - Wt Pan	93.8	94.1	93.6	94.2	93.4
I - Wt. Dry Soil	256.4	273.0	243.2	245.0	240.4
- Speedy Method -					
Dial Reading - Sample Size					
J - % Moisture - Wet Wt.					
K - % Moisture - Dry Wt.	13.8	15.0	17.0	18.2	19.7
L - Dry Density kg/m³ (lb/ft³)	1702	1732	1738	1721	1664

Calculations: C= A-B:, D= (1059.43)C (M) or D=(30)C (E)

G=E - F; I=F-H

K=G/Ix100 or K=J/(I-J/100) L=(D/100+K)100

See Grading and Base Manual Fig 5 5-692.222 (M)

See Grading and Base Manual Fig 5 5-692.222 (E)

Remarks; % Ret. 4.75 mm (#4) ______ M_f ______ D_f ______

Soils Class SiCL

Tester A. Okay

cc:Project File

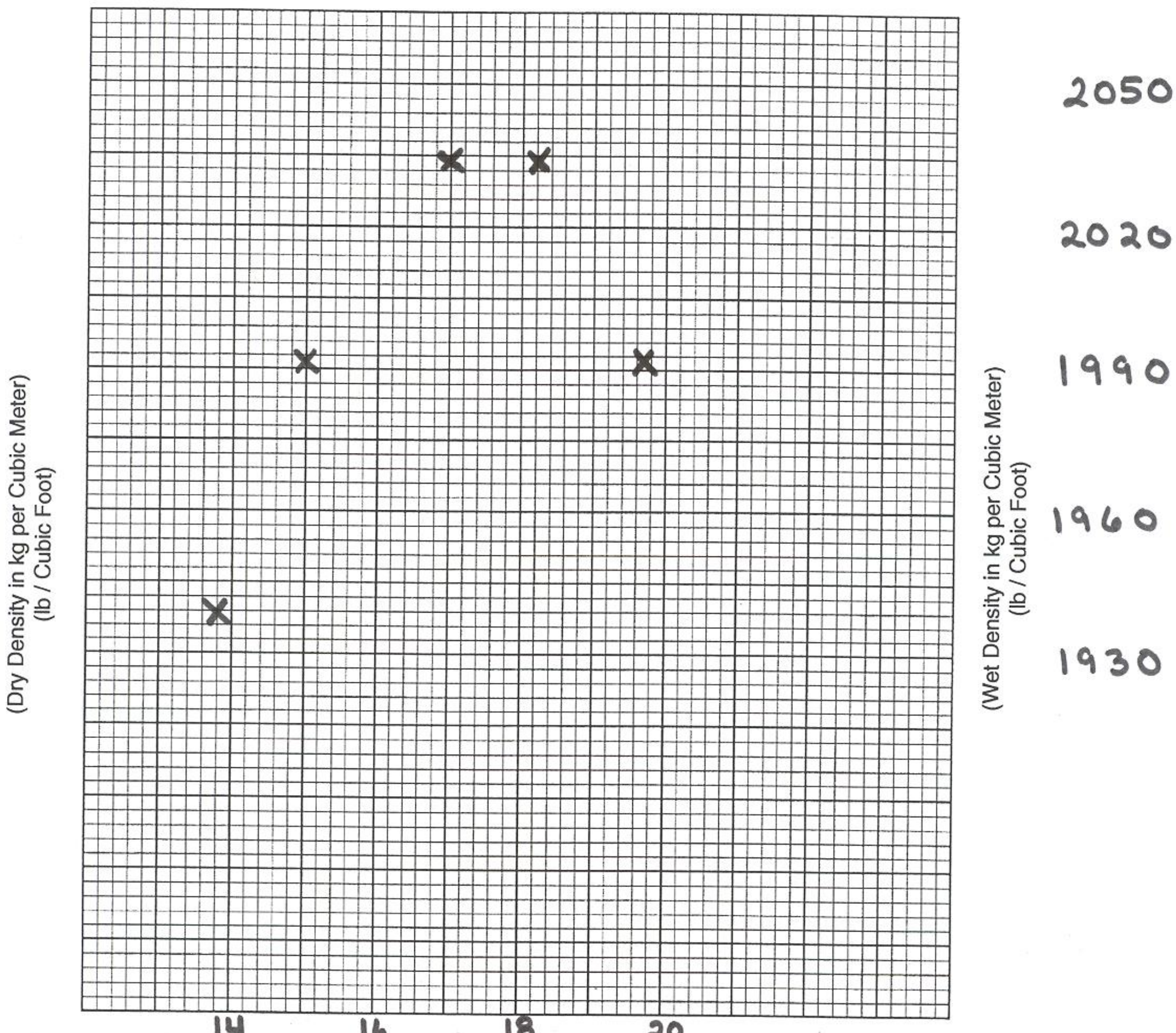
Minnesota Department of Transportation TP-02430-03 (6/2002)

Office of Materials and Road Research

Moisture-Density Relationship

Sample No: 17 Date: 8-12-01 Tester: Max Density

Curve No: 6 Soil Class: SiCL



Optimum Moisture: ______ Maximum Density ______

Remarks: ______

cc: Project File

See Grading & Base Manual, Fig. 6-9 5-692.222 (Metric)
See Grading & Base Manual, Fig. 6-9 5-692.222 (English)

Fig. 6 5-692.22

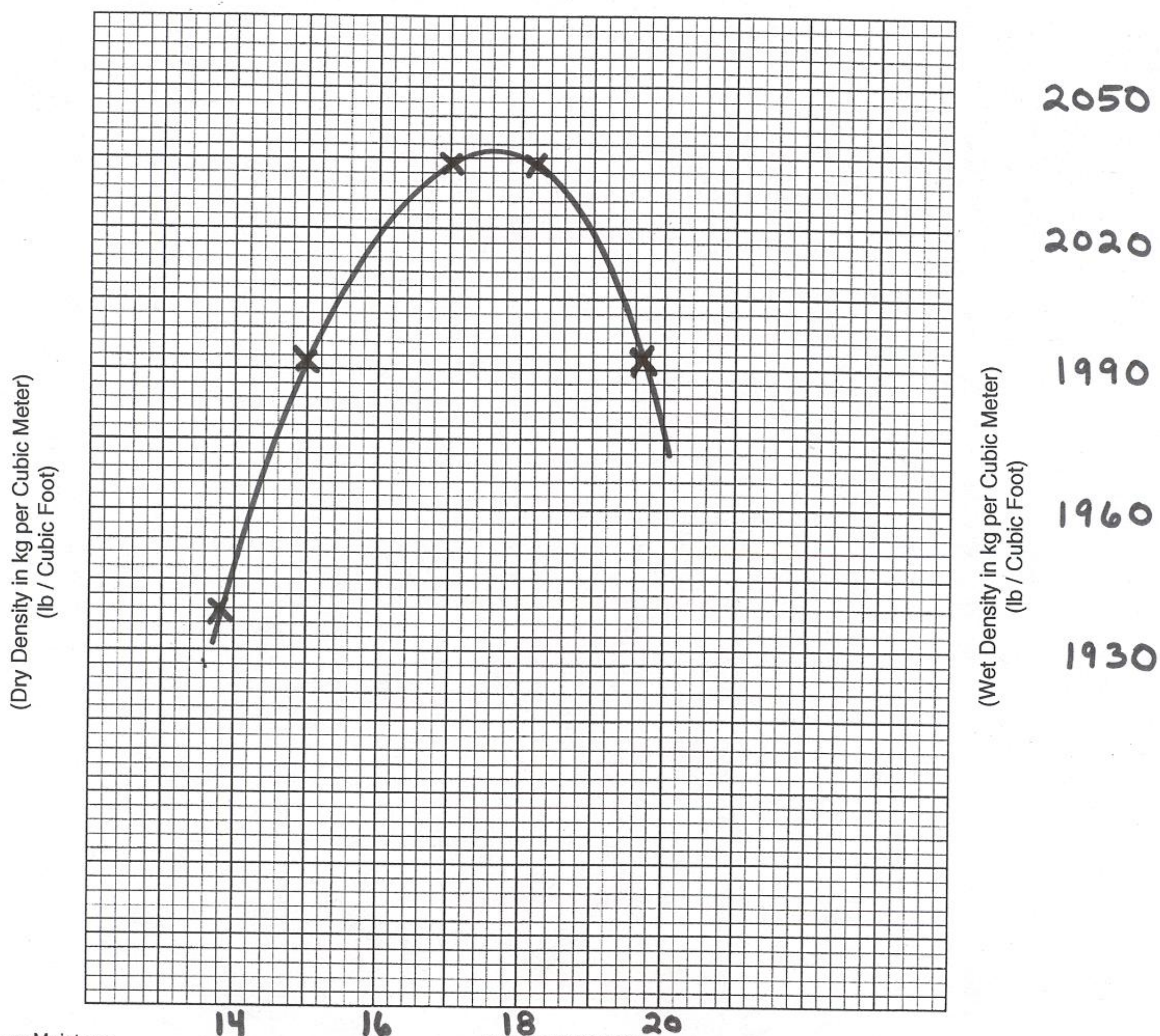
Minnesota Department of Transportation TP-02430-03 (6/2002)

Office of Materials and Road Research

Moisture-Density Relationship

Sample No: 17 Date: 8-12-01 Tester: Max Density

Curve No: 6 Soil Class: SiCL



Optimum Moisture: ______ Maximum Density ______

Remarks: ______

cc: Project File

See Grading & Base Manual, Fig. 6-9 5-692.222 (Metric)
See Grading & Base Manual, Fig. 6-9 5-692.222 (English)

Fig. 7 5-692.222M

Minnesota Department of Transportation

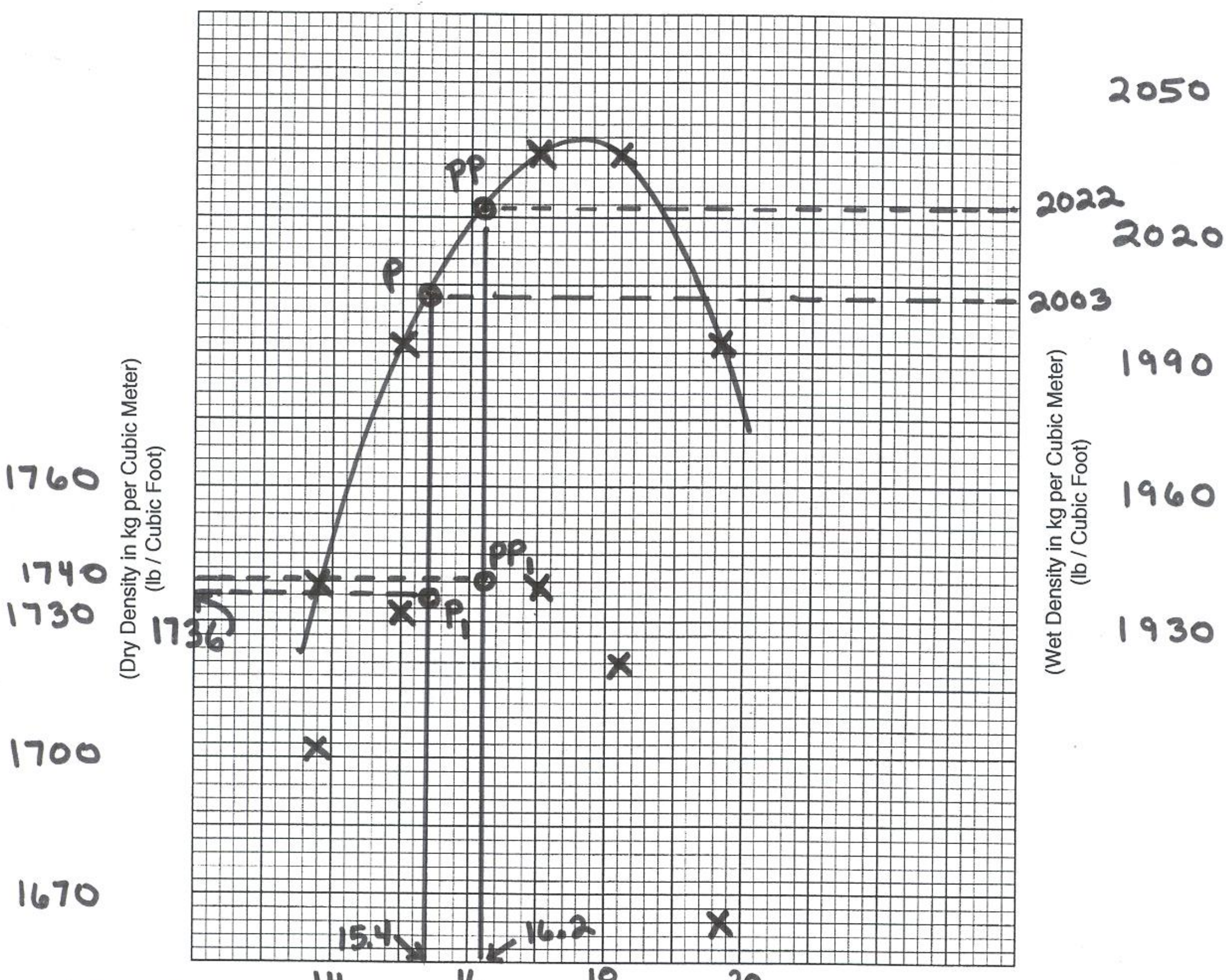
Office of Materials and Road Research

TP-02430-03 (6/2002)

Moisture-Density Relationship

Sample No: 17 Date: 8-12-01 Tester: Max Density

Curve No: 6 Soil Class: SiCL



Optimum Moisture: ________ Maximum Density ________

Remarks: ________

cc: Project File

See Grading & Base Manual, Fig. 6-9 5-692.222 (Metric)
See Grading & Base Manual, Fig. 6-9 5-692.222 (English)

Fig. 8 5-692.222M

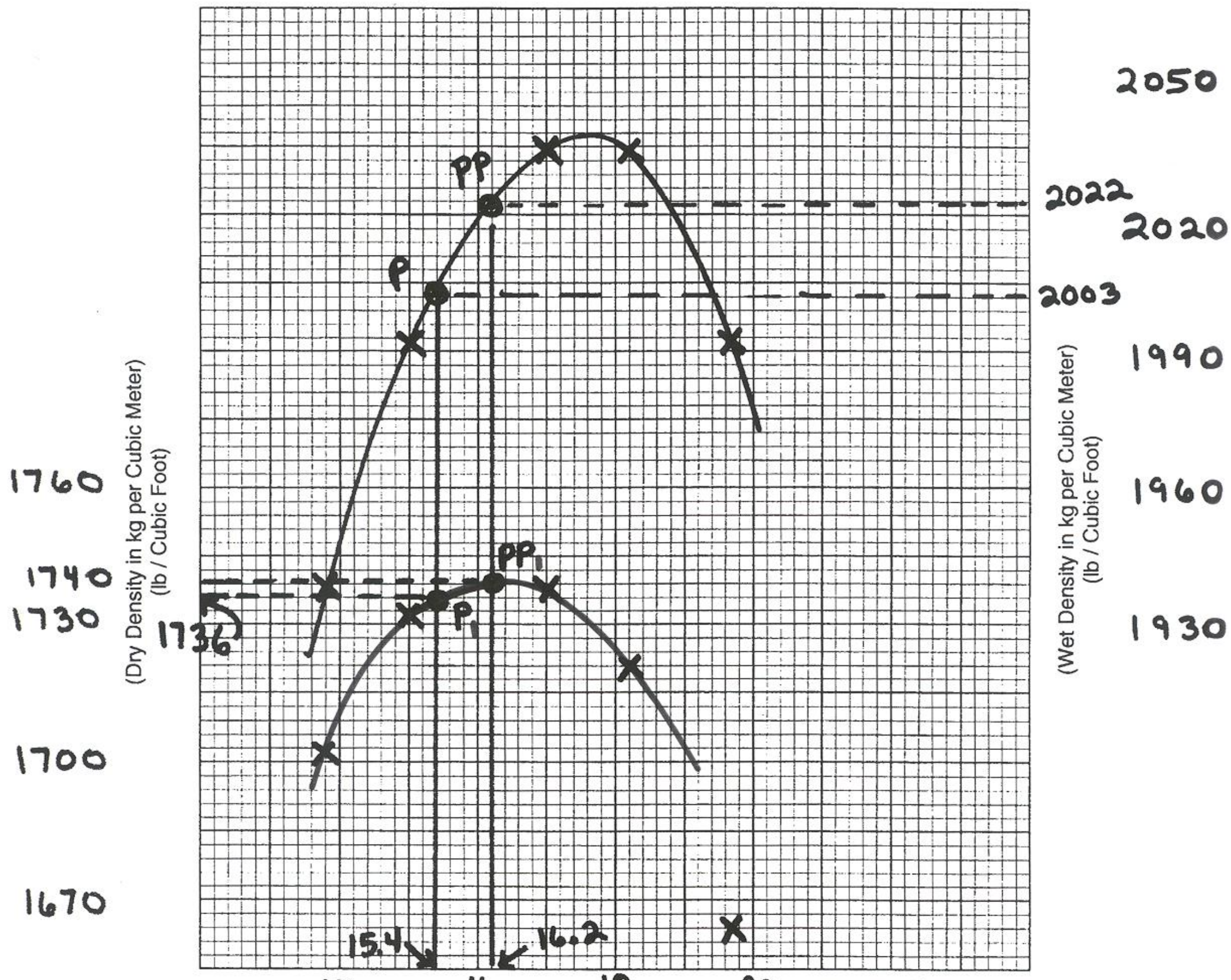
Minnesota Department of Transportation TP-02430-03 (6/2002)

Office of Materials and Road Research

Moisture-Density Relationship

Sample No: 17 Date: 8-12-01 Tester: Max Density

Curve No: 6 Soil Class: SiCL



Optimum Moisture: 16.2 Maximum Density 1740

Remarks:

cc: Project File

See Grading & Base Manual, Fig. 6-9 5-692.222 (Metric)
See Grading & Base Manual, Fig. 6-9 5-692.222 (English)

Fig. 9 5-692.222M

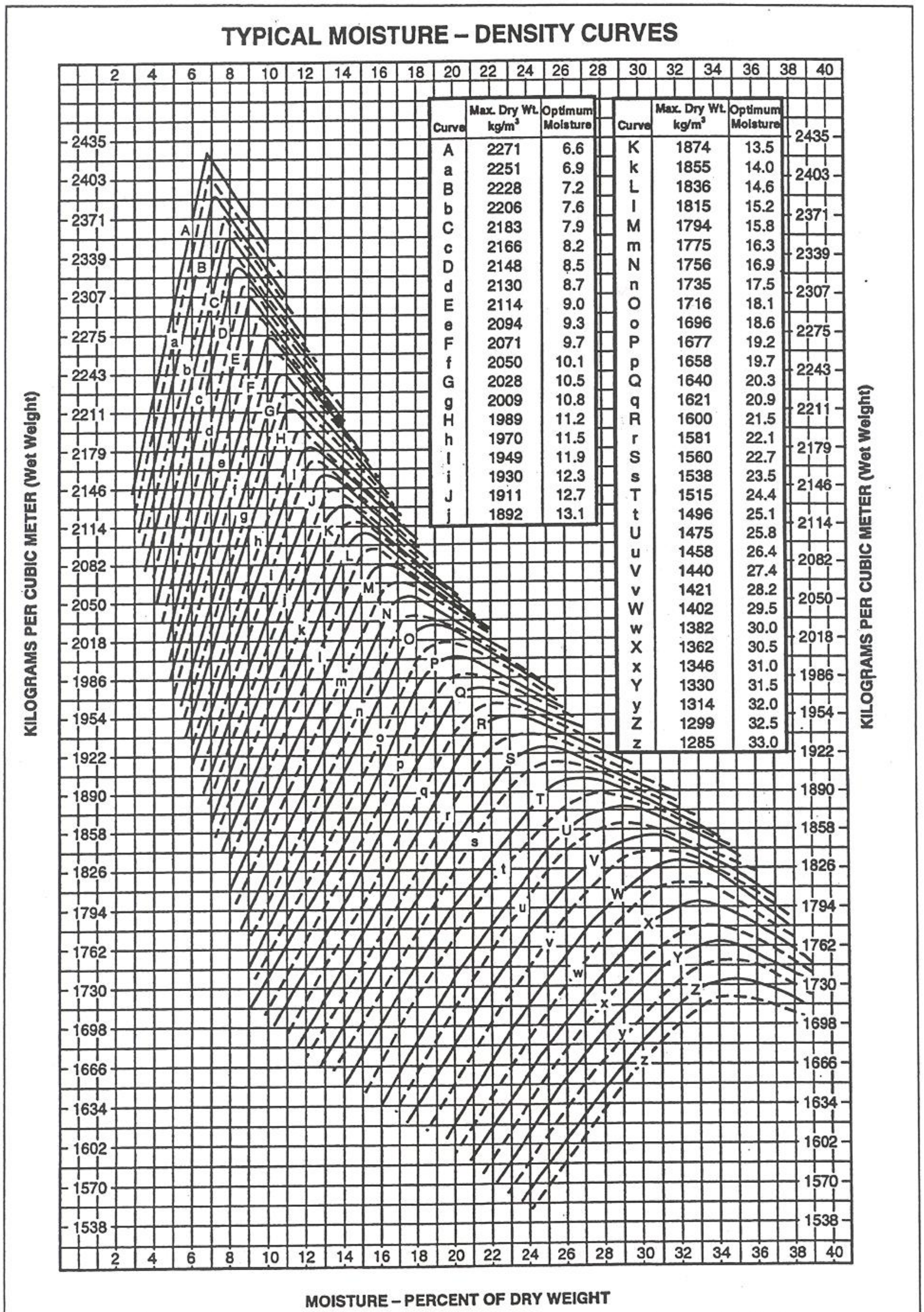


Fig. 10 5-692.222M

5-692.222E MOISTURE-DENSITY TEST METHOD (PROCTOR) (ENGLISH)

Note: Moisture-Density Test (Proctor) Tolerances
All required laboratory Proctor samples shall have a field tested companion sample. Both samples must be split from the same larger sized sample. The field and laboratory Proctor test samples shall be of nearly equal size after spliting. Both **maximum density** tests shall correspond within **50kg/m3 (3 lbs./cu.ft.)** from field to laboratory test and both **optimum moisture** tests shall correspond within **2%**. Any testing exceeding these tolerances will require immediate action to determine the cause of the "out of tolerance" problem.

A. This Moisture-Density Test (Proctor) is a method of determining the relationship between the moisture content and the density of the grading soil, base or subbase aggregate when compacted by following a standard procedure. This method is consistent with AASHTO T-99, Method C.

The Maximum Density is the highest dry density that can be obtained by varying the moisture contents and compacting the material by following a standard procedure. The Optimum Moisture content is the moisture content (expressed as percent of dry weight) of the soil, base or subbase aggregate at the Maximum Density. When compaction is controlled by the Specified Density Method, the moisture content of the soil or aggregate being placed is compared to the Optimum Moisture content and the density of the in-place compacted material is compared to the Maximum Density to determine compliance with the specification requirements. The moisture content of the soil or aggregate compared to the Optimum Moisture content of the same soil indicates the amount of compactive effort needed to achieve the Specified Density. A soil with a moisture content lower than the Optimum Moisture requires more compactive effort than the same soil with a moisture content near "optimum". Soils with moisture contents higher than "optimum" tend to be unstable and may be impossible to compact.

When the Quality Compaction Method is required, knowledge of the optimum moisture and maximum density for the material helps the inspector determine the moisture necessary for proper compaction.

B. **Apparatus (English)**

1. Proctor mold - A cylindrical metal mold having a capacity of 1/30 cu. ft. with an internal diameter of 4 inches and a height of 4.584 ± .006 inches. The mold shall have a detachable collar assembly and base plate.
(Figure 1 5-692.222E).
2. Rammer - Metal rammer having a flat circular face of 2 inch diameter and weighing 5.5 lbs. The rammer shall be equipped with a guide-sleeve to control the height of drop to a free fall of 12 inches above the soil. (Figure 2).
3. Platform scale - The platform scale shall have a minimum capacity of 30 lbs.; it shall be sensitive to 0.01 lb. and the minor graduations on the indicator shall be 0.01 lb.

4. Balance - The balance shall have a minimum capacity of 2500 grms; it shall be sensitive to 0.1 gm and the minor gradations on the indicator shall be for 0.1 gm.
5. Drying oven or stove.
6. Mixing tools. (Figure 3).
7. Spatula and butcher knife. (Figure 3).
8. Box sieves, 2”, 3/4”, 3/8”, No. 4 with bottom pan.

9. Concrete compaction base. A block of concrete weighing not less than 100 lbs. supported on a stable foundation; a sound concrete floor or other solid surface found in concrete box culverts, bridges and pavement. See Figure 4 for typical test equipment set-up.

C. Sample Preparation

Step 1. Obtain a sample of the soil or aggregate according to the procedures described in 5-692.221.

Step 2. If the soil sample is damp, dry it until it becomes friable under a trowel. The sample may be air dried or dried in the oven or on the stove such that the temperature does not exceed 140ºF.

Step 3. Sieve an adequate quantity of the sample over the 2”, 3/4” and No. 4 on bottom pan. Break up all soil lumps to pass the sieves.

Step 4. Discard the stones retained on the 2” sieve.

Step 5. Weigh the stones that pass the 2” sieve and are retained on the 3/4” sieve.

Step 6. Discard the stones retained on the 3/4” sieve and replace them with an equal weight of stones passing the 3/4” sieve and retained on the No. 4 sieve.

> **Note:** The replacement material may be obtained from the remaining portion of the sample, a companion sample or completed gradation sample.

Step 7. If the sample contains soil lumps and clay balls, pulverize them so they pass through the No. 4 sieve.

> **Note:** When a large portion of the sample consists of lumps, use a 3/8” sieve as well as the No. 4.

Step 8. Recombine any stones retained on the No. 4 (and 3/8”) sieve(s) with the pulverized material in the pan.

Step 9. Select about 12 lb. or more of the prepared sample using a procedure described in 5-692.212, .213 or .214.

D. **PROCTOR METHOD** (Multi-Point)

This test consists of compacting a portion of a soil sample in a mold at different moisture contents ranging from dry to wet. **At least 4 samples** will be run. The samples will differ in moisture content by one to two percent with the driest sample being about four percentage points below optimum moisture. This would result in two of the samples being below optimum, one near optimum and one over optimum. A valid test will have 2 points below optimum.

1. **Standard Method**

Step 1. Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately 4 percentage points below optimum moisture content.

> **Note:** To estimate the starting point for granular soils (less than 20% passing the No. 200 sieve), moisten and mix the soil until it can be squeezed into a ball or "cast". The cast should crumble easily when touched. Soils with more than 20% passing the No. 200 sieve usually have higher optimum moisture than granular soils and the cast is less easily crumbled at the starting point.

Step 2. Determine the weight of the mold and base plate. Record the weight as "B-Wt. Mold". See Figure 5, 5-692.222. DO NOT INCLUDE THE WEIGHT OF THE COLLAR.

Step 3. Place the assembled mold, including collar, on the concrete compaction base.

Step 4. Place enough of the sample into the mold for one layer.

> **Note:** The mold is filled with three equal layers of compacted material. After compaction, the top layer should be about 1/2" over the top of the mold when the collar is removed.

Step 5. Compact the loose material by 25 uniformly distributed blows from the rammer dropping freely from a height of 12" above the soil.

Step 6. Repeat Steps 4 and 5 until the three layers are placed and compacted.

Step 7. Remove the collar and carefully trim the compacted soil with the knife until it is even with the top of the mold (check with the spatula). Remove any stones dislodged by trimming and fill the holes by carefully pressing finer material into place. Trim around any stones that are at least half buried and solidly seated.

Step 8. Clean all the loose material from the mold and base plate and weigh it on the platform scale to the nearest gram. Record the weight as "A-Wt. Wet Soil + Mold".

Step 9. Remove the mold from the base plate and loosen the locking devices so that the compacted material can be removed from the mold.

Step 10. Quarter the compacted material by slicing twice vertically through the compacted soil. Select one of the quarters and weigh immediately. Conduct the moisture determination according to the procedure in 5-692.245.

> **Note:** A representative sample must consist of nearly equal portions of material from all three layers. When the "Speedy" method is used, take the sample the same way as the burner dry method and use a representative portion for the moisture determination.

Step 11. Thoroughly break up any remaining portion of the molded specimen and add it to the sample being tested.

Step 12. Add enough water to increase the moisture content about two percentage points.

> **Note:** 90 cc, mls or grams of water will increase the moisture content of 10 lb.of material about two percentage points. Additional water may be needed to replace moisture lost by evaporation during mixing.
>
> **Note:** In each repetition the material shall be thoroughly mixed before compaction to assure uniform dispersion of the moisture throughout the sample.

Step 13. Repeat Steps 4 thru 12 until the "Wt. Wet Soil + Mold" determined in Step. 8 either decreases or fails to increase. At this point the compacted material should be soft and spongy; granular material may not be very spongy but will be extremely wet. The spongy condition indicates that the moisture content of the sample exceeds optimum.

2. **Alternate Method**

The above procedure is satisfactory in most cases. However, if the soil is fine grained, cohesive and difficult to break up and mix with water or if the material is fragile and will reduce significantly in grain size due to repeated compaction, use the following procedure:

Step 1. Prepare the sample as outlined in Paragraph C, Steps 1 thru 8.

Step 2. Select about 11 kg of the prepared material using a procedure described in 5-692.212, .213 or .214.

Step 3. Moisten or dry the sample to about four percentage points below the estimated optimum moisture. See "Note" Step 1 in Paragraph D above.

Step 4. Divide the sample into four or five portions of about 5 lb. each

Step 5. Place one portion into a water tight container, cover, set aside, and mark as "point No. 1".

Step 6. Add enough water to one of the remaining portions to increase the moisture content about two percentage points. (45 mls., cc or grams of water added to 5 lb. of material will increase the moisture content 2.0 percent.) Place this portion in a container and mark as "point No. 2".

Step 7. Continue this process with the remaining two or three portions and increase the amount of water each time until there is a series of points at about 2, 4, 6, and 8 percentage points over "point No. 1". At least one "point" should exceed the estimated optimum moisture.

Example: A clay loam soil is to be tested. It is coming from the cut of about 20% moisture. The estimated optimum moisture is about 18%. It is necessary to dry the soil to about 8% moisture before it can be pulverized. After the soil is pulverized, the inspector mixes 25 lb. of soils with enough water (450 cc) to bring it to about 12% moisture. The inspector divides the sample into five samples. weighing about 5 lb. each, and places them into concrete cylinder molds labeled "point No. 1", "point No. 2", etc. "Point No. 1" is covered and set aside. He adds 45 cc of water to No. 2, 90 cc to No. 3, 135 cc to No. 4 and 180 cc to No. 5, mixes, covers and sets them aside.

Step 8. Allow the covered material to "soak" in the molds overnight (twelve hours minimum) to permit the moisture to disperse through the soil.

Step 9. Compact each portion following Step 2 through 10 of the Standard Method.

Note: In heavy clay or organic soils exhibiting flat enlongated curves are encountered, the water content increments may be increased to a maximum of 4 percent.

E. Calculations (Refer to Figure 5 5-692.222E)

1. Wet Density
   A = Wt. Wet Soil + Mold lb.
   B = Wt. Mold lb.
   C = Wt. Wet Soil (A-B)
   D = Wet Density, lb. Per cu. ft. (C x 30)

   Note: 30 = Number of "mold castings" per cu. ft.

   Example:
   A = 16.44 lb.
   B = 12.41 lb.
   C = 16.44 – 12.41 = 4.03 lb.
   D = 4.03 x 30 = 120.9 lb./cu. ft.

2. Percent Moisture Burner Method
   E = Wt. Wet Soil + Pan grams
   F = Wt. Dry Soil + Pan grams
   G = Wt. Moisture (E-F)
   H = Wt. pan, grams
   I = Wt. Dry Soil (F-H)
   J = % Moisture, Wet Wt. - [G/(E-H)] x 100
   K = % Moisture, Dry Wt. = (G/I) x 100

Example:

E = 385.6 grams
F = 350.2 grams
G = 385.6 - 350.2 = 35.4 grams
H = 93.8 grams
I = 350.2 - 93.8 = 256.4 grams
K = (35.4/256.4) x 100 = 13.8%

3. Speedy Method

If the % Moisture, Wet Wt. (J) is recorded, determine and record the % Moisture, Dry Wt. (k) by using Table A 5-692.250 or the following formula:

$$K = \frac{J}{1.0 - \left(\frac{J}{100}\right)}$$

Example:

J = 12.3 (gauge reading from Speedy Moisture Meter)

$$K = \frac{12.3}{1.0 - \left(\frac{12.3}{100}\right)} = 14.0\%$$

4. Dry Density

L = Dry Density, lb. per cu. ft.

[D/(100 + K)] x 100

Example: L = [120.9/(100 + 13.8)] x 100 = 106.2

F. The Maximum Density and Optimum Moisture Content

The Maximum density and optimum moisture are determined by graphing the information obtained by compacting the samples at various moisture contents. Each moisture content relates to a wet density and to a dry density.

Example: (From Fig.5 5-692.222E)

	Point				
	No. 1	No. 2	No. 3	No.. 4	No. 5
D. Wet Density	120.9	124.2	126.9	126.9	124.2
K. % Moisture	13.8	15.0	17.0	18.2	19.7
L. Dry Density	106.2	108.0	108.5	107.4	103.8

Important Notice: The drawing of the "wet" curve is not required if the laboratory tester has compacted four adequate points as described previously. But, if the "wet" curve is not drawn, the "dry" curve must be computer generated. All discrepancies between companion samples shall be resolved by plotting the "wet" curve by hand and interpolating the "dry" curve points as shown below.

Step 1. Plot the wet densities against the moisture contents on a Form 2430. (Figure 6).

Step 2. Draw a smooth curve thru the plotted points. (Figure 7). This is the “wet curve”.

Step 3. Plot the dry densities against the moisture contents. (Figure 8). Additional “dry points” may be interpolated from the “wet curve”.

Example: In Figure 8, Points P and PP are used to establish points P_1 and PP_1 on the “dry curve”.

D. (Wet Density) for Point P = 125.0 lb./cu. ft.
K. (Moisture) for Point P and P_1 = 15.4%.
L. (Dry Density) for point P_1 = [125.0/(100 + 15.4)] x 100 = 108.3 lb./cu. ft.

and

D. (Wet Density) for Point PP = 126.2 lb./cu. ft.
K. (Moisture) for Point PP and PP_1 = 16.2%.
L. (Dry Density) for point PP_1 = [126.2/(100 + 16.2)] x 100 =108.6 lb./cu. ft.

Step 4. Draw a smooth curve thru the plotted points. (Figure 9). This is the “dry curve”.

Step 5. Read the maximum density and optimum moisture from the peak of the “dry curve”. (Figure 9). Maximum Density = 108.6 lb./cu. ft.; Optimum Moisture = 16.2%.

Note: Figure 10 is an example of computer generated proctor curves and does differ very slightly from the hand drawn version of figure 9.

G. PROCTOR (One-Point Method)

Use this method for determining the standard maximum density and optimum moisture on grading soils only and never on base or subbase aggregates. Also, this method is for field testing only. Never use the one-point Proctor method in lieu of a "multi-point" moisture-density test on a Project's major grading soil. Use the one-point method to analyze subtle changes occurring between major grading soils. Slight changes in color, texture, structure, etc. (See 5-692.600) may indicate these changes. Also, use one-point Proctors to verify changes in maximum density and optimum moisture indicated by relative densities (sand cone tests) failing to meet specified density requirements even though operations have not changed and previous tests have passed. Relative density tests exceeding 106 percent suggest zero air voids and indicate a possible change in maximum density. Run a one-point Proctor to confirm the suspected change. Use the "multi-point" moisture density test for the material closest to the soil with this subtle change to check the testing accuracy of the one-point Proctor. A reasonable variation should not exceed plus or minus 3 pounds per cubic foot. If the variation exceeds 3 pounds, run another "multi-point" Proctor.

Step 1. Obtain a representative sample of soil from the fill area. (See 5-692.221).

Note: 3 to 6 lbs. of “minus No. 4” material is usually enough to complete the test; however, it may be necessary to take much more than 6 lbs. to have a ”representative" sample.

Step 2. Sieve the sample through a No. 4 sieve. If it is necessary to dry the sample, do not allow it to become "oven" or "stove" dry. Be sure to pulverize all clay lumps.

Step 3. Weigh the stones retained on the No. 4 sieve, record the weight and discard the stones.

Step 4. Weigh the portion of the sample passing the No. 4 sieve. Record the weight.

Step 5. Calculate the percent of the sample retained on the No. 4 sieve as follows:

$$C = \frac{A}{A + B} \times 100$$

C = % retained on the No. 4 sieve.
A = Wt. of plus No. 4 material (Step 3)
B = Wt. of minus No. 4 material (Step 4)

Example:
A = 2.20 lbs.
B = 9.75 lbs.

$$C = \frac{2.20}{2.20 + 9.75} \times 100$$

$$C = 18\%$$

Step 6. Reduce the size of the minus No. 4 portion of the sample to about 6 lbs. by quartering or splitting (5-692.212 or 5-692.214).

Step 7. Add water to the reduced sample and mix thoroughly until the material is damp enough to compact well; do not add so much water that the soil becomes "spongy" when compacted.

Step 8. Determine the weight of the mold and base plate. Record the weight.

Step 9. Place the assembled mold, including the collar, on the compaction base.

Step 10. Scoop enough material into the mold for 1 layer.

Note: The mold is filled with 3 equal layers of compacted material; the top layer, after compaction, should be about 1/2" over the top of the mold when the collar is removed.

Step 11. Compact the loose material with 25 evenly distributed blows with the rammer dropped from 12 inches.

Step 12. Repeat Steps 10 and 11 until 3 layers are inplace.

Step 13. Remove the collar and trim the compacted material with a knife until even with the top of the mold. (Check with a spatula.)

Step 14. Brush all loose material from the mold and base plate and weigh the mold to the nearest 0.01 lb. on the platform scale. Record the weight.

Step 15. Calculate the wet weight per cubic foot of the compacted material.

F = 30 (D-E)
F = Wet wt. per cu. ft.
D = Weight of wet soil and mold (Step 14).
E = Weight of the mold (Step 8).

Example:

D = 16.71 lbs., E = 12.50 lbs.
F = 30 (16.71 – 12.50)
F = 126.3 lbs./cu. ft.

Step 16. Remove the mold from the base plate and loosen the locking devices so the compacted material can be removed from the mold.

Step 17. Select a representative sample for a moisture test. Conduct the test according to the procedures in 5-692.245. Record the results.

Step 18. Using the Typical Moisture Density Curves (Fig. 11 5-692.222E) determine the optimum moisture and maximum density of the minus No. 4 material.

Example:

Given: Wet wt. per cu. ft. = 126.3 lbs. (Step 15)
Moisture = 14.1% (Step 17).

Follow the horizontal line representing the wet weight (126.3) across the chart until it intersects the vertical line representing the moisture (14.1). The Typical Curve lying nearest the point of intersection ("M") represents the maximum density and optimum moisture of the minus No. 4 material. For curve M, the maximum dry density is 112.0 lb./cu. ft. and the optimum moisture is 15.8%.

Step 19. If the amount of plus No. 4 material determined by Step 5 exceeds 5%, the maximum density and optimum moisture of the minus No. 4 material must be adjusted to account for the plus No. 4 portion of the representative sample. The density is adjusted by the following calculation:

H = (1.0-C)G + 148.8(C)
H = Maximum Density of the total sample.
G = Maximum Density of the minus No. 4 portion.
C = % retained on the No. 4 sieve, expressed as a decimal.

Example:

Given:

$G = 112.0$; $C = 18\% = 0.18$

$H = (1.0-0.18)\ 112.0 + 148.8\ (0.18)$

$H = 118.6$ lb./cu. ft.

The Optimum Moisture is adjusted by the following calculation:

$J = 2(C) + (1.0-C)I$

J = Optimum Moisture of the total sample.

I = Optimum Moisture of the minus No. 4 portion.

C = % retained on the No. 4 sieve, expressed as a decimal.

Example:

Given:

$I = 15.8\%$; $C = 18\% = 0.18$

$J = 2(0.18) + (1-0.18)15.8$

$J = 13.3$

The Standard Maximum Density and Optimum Moisture for the sample selected in Step 1 is 118.6 lb./cu. ft. and 13.3%.

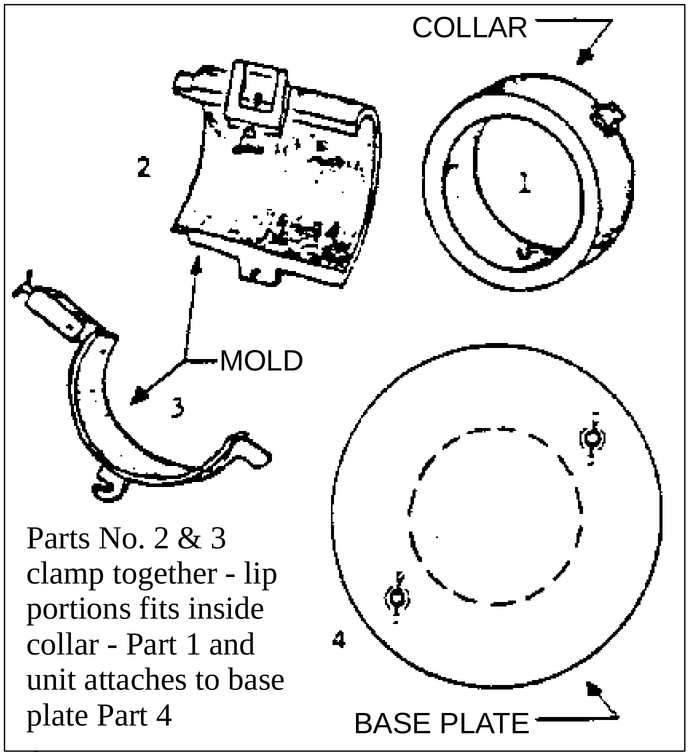


Figure 1 - Mositure-Density Test Mold

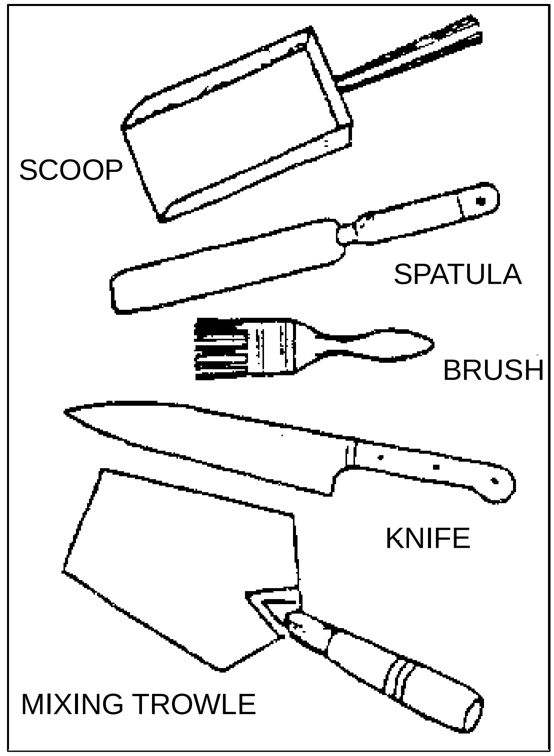


Figure 3 - Typical Tools

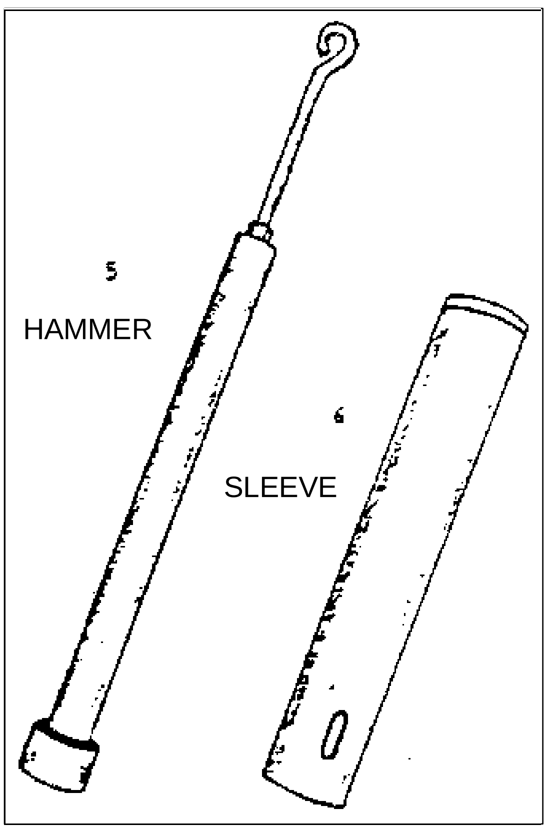


Figure 2 - Rammer

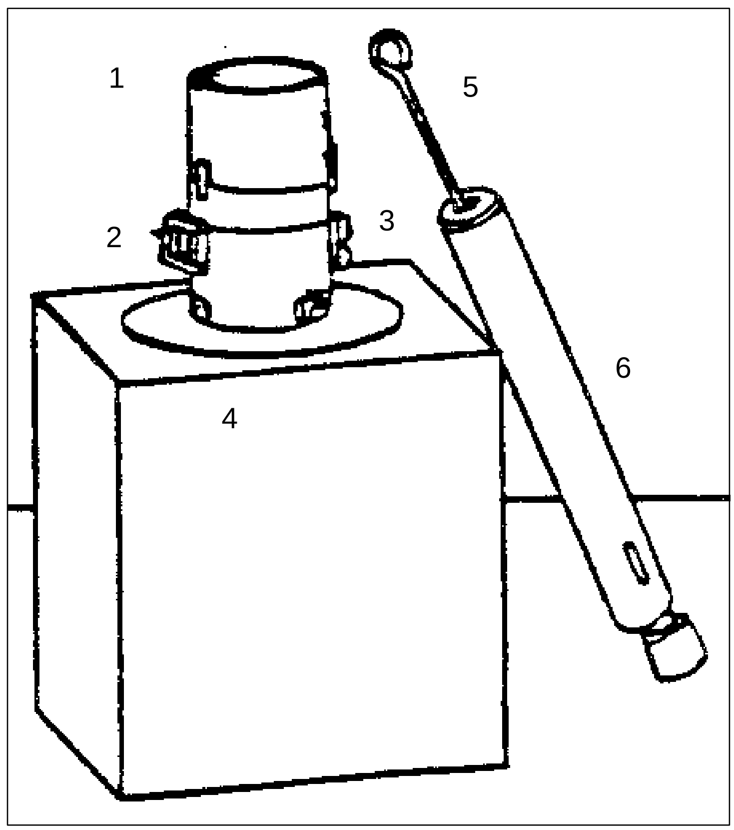


Figure 4 - Typical Set-up for Moisture-Density Test

TP-24587-01 (3/13/02)

Minnesota Department of Transportation

Office of Materials and Road Research

Calculation for Moisture - Density Relationships in Subgrade Soils and Aggregate Base and Shoulders

Units Metric

Sample No: 7	Curve No: 3	Date: 7-10-01
		S. P. No: 1403-09

Optimum Moisture (M_t) 16.2 %
Maximum Density (Dt) 108.6 kg/m³ (lb/ft³)

A - Wt. Wet Soil + Mold	16.44	16.55	16.64	16.64	16.55
B -Wt. Mold	12.41	12.41	12.41	12.41	12.41
C - Wt. Wet Soil	4.03	4.14	4.23	4.23	4.14
D - Wet Density kg/m³ (lb/ft³)	120.9	124.2	126.9	126.9	124.2
- Burner Method -					
E - Wt. Wet Soil + Pan	385.6	408.1	378.1	383.8	381.2
F - Wt. Dry Soil + Pan	350.2	367.1	336.8	339.2	333.8
G - Wt Moisture	35.4	41.0	41.3	44.6	47.4
H - Wt Pan	93.8	94.1	93.6	94.2	93.4
I - Wt. Dry Soil	256.4	273.0	243.2	245.0	240.4
- Speedy Method -					
Dial Reading - Sample Size					
J - % Moisture - Wet Wt.					
K - % Moisture - Dry Wt.	13.8	15.0	17.0	18.2	19.7
L - Dry Density kg/m³ (lb/ft³)	106.2	108.0	108.5	107.4	103.8

Calculations: C= A-B:, D= (1059.43)C (M) or D=(30)C (E)
G=E - F; I=F-H
K=G/Ix100 or K=J/(I-J/100) L=(D/100+K)100

See Grading and Base Manual Fig 5 5-692.222 (M)
See Grading and Base Manual Fig 5 5-692.222 (E)

Remarks; % Ret. 4.75 mm (#4) ________ M_f ________ D_f ________

Soils Class SiCL

Tester Cory Atfe

cc:Project File

Fig. 5-692.222E

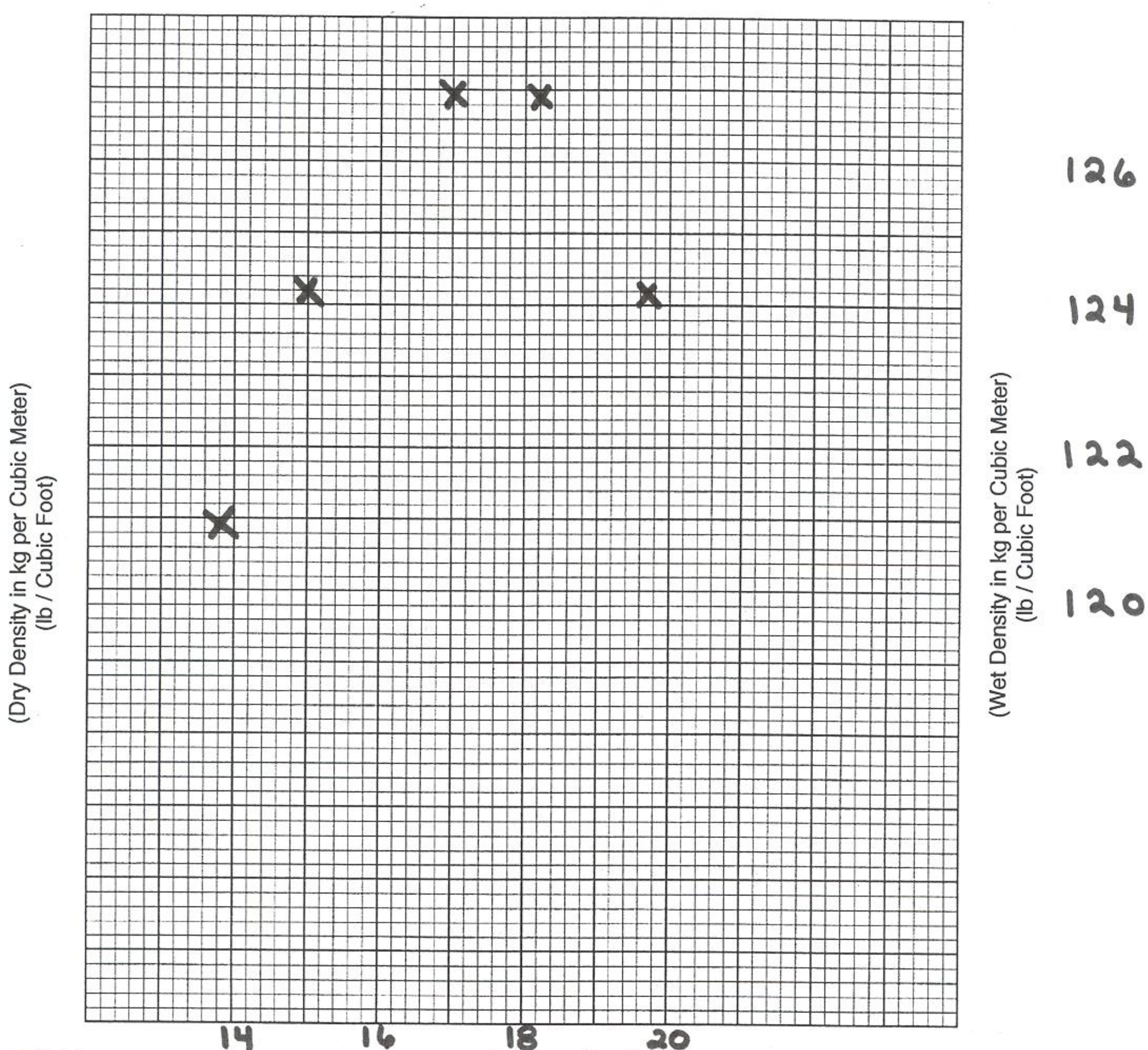
Minnesota Department of Transportation TP-02430-03 (6/2002)

Office of Materials and Road Research

Moisture-Density Relationship

Sample No: 7 Date: 7-10-01 Tester: Cory Afte

Curve No: 3 Soil Class: Si CL



Optimum Moisture: ____________ Maximum Density ____________

Remarks: ____________

cc: Project File

See Grading & Base Manual, Fig. 6-9 5-692.222 (Metric)
See Grading & Base Manual, Fig. 6-9 5-692.222 (English)

Fig. 6 5-692.222E

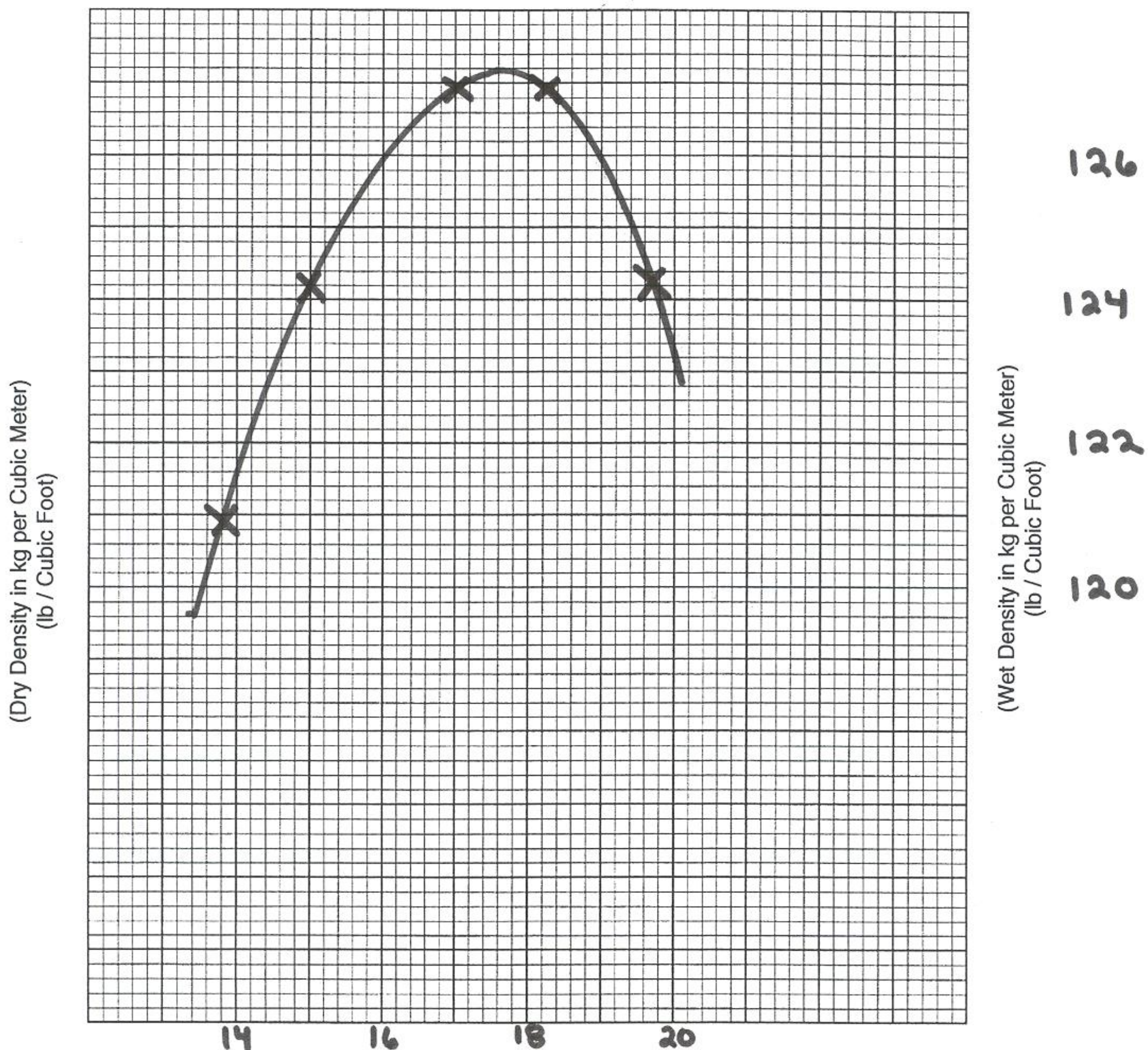
Minnesota Department of Transportation TP-02430-03 (6/2002)

Office of Materials and Road Research

Moisture-Density Relationship

Sample No: 7 Date: 7-10-01 Tester: Cory Atfe

Curve No: 3 Soil Class: Si CL



Optimum Moisture: ______ Maximum Density ______

Remarks: ______

cc: Project File

See Grading & Base Manual, Fig. 6-9 5-692.222 (Metric)
See Grading & Base Manual, Fig. 6-9 5-692.222 (English)

Fig. 7 5-692.222E

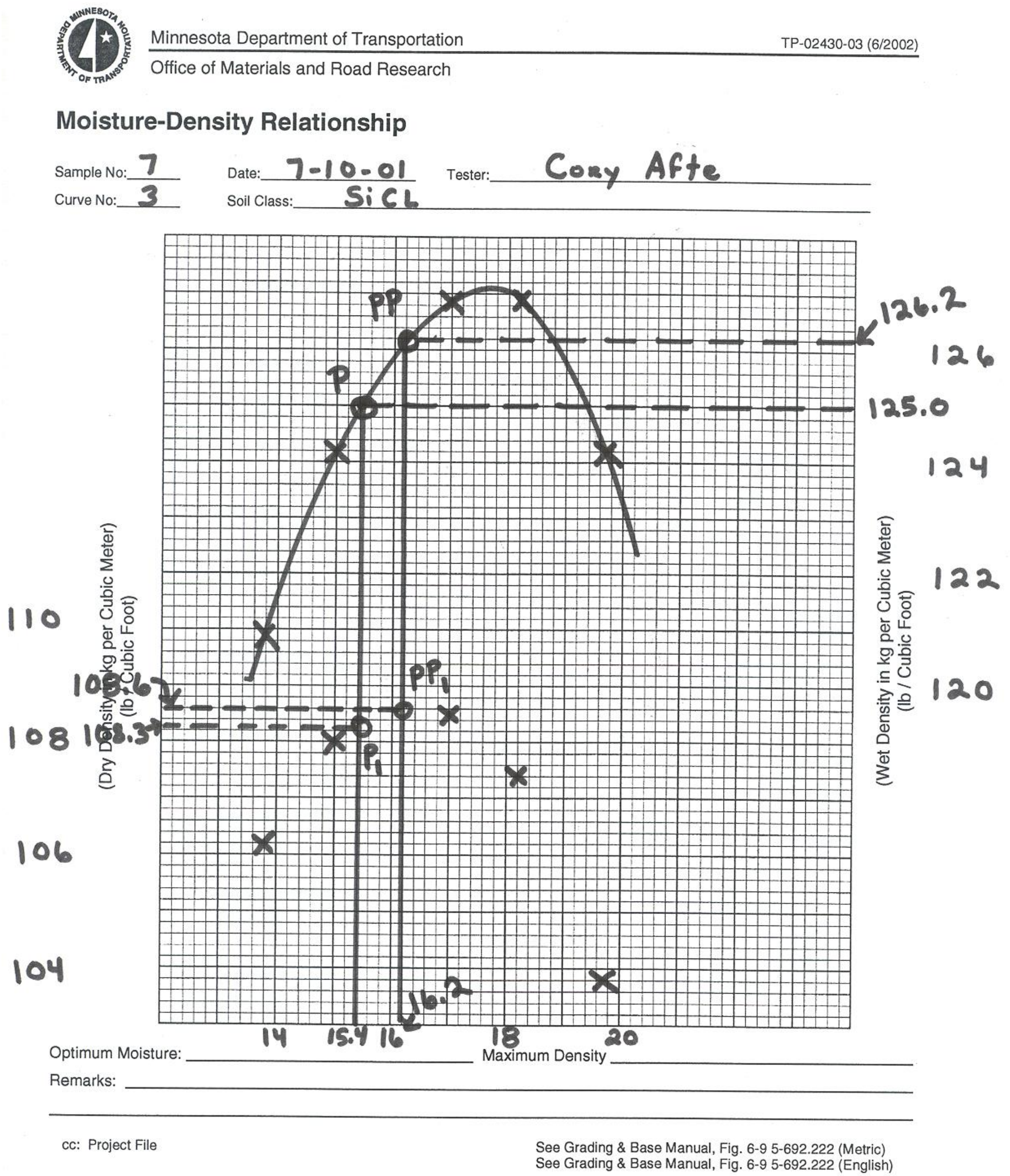


Fig. 8 5-692.222E

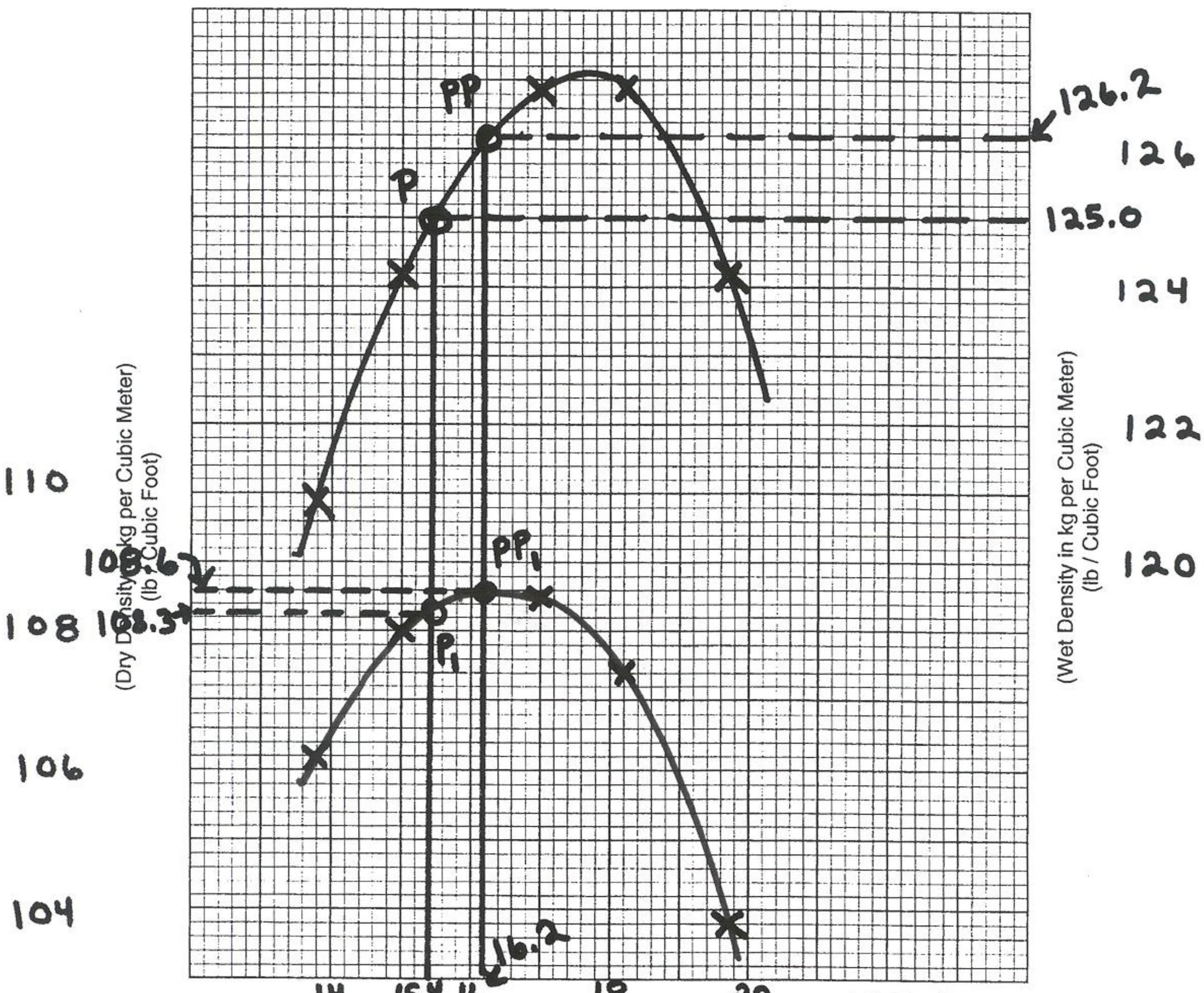
Minnesota Department of Transportation TP-02430-03 (6/2002)

Office of Materials and Road Research

Moisture-Density Relationship

Sample No: 7 Date: 7-10-01 Tester: Cory Afte

Curve No: 3 Soil Class: SiCL



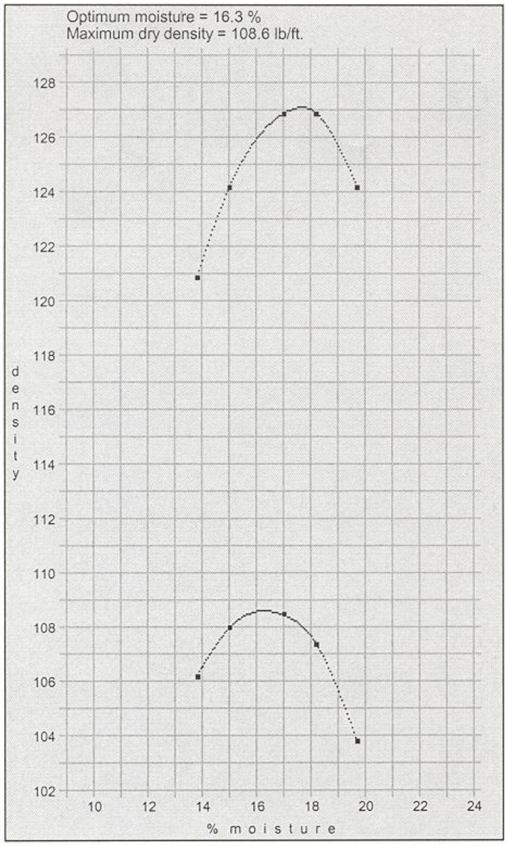
Optimum Moisture: 16.2 Maximum Density 108.6

Remarks:

cc: Project File

See Grading & Base Manual, Fig. 6-9 5-692.222 (Metric)
See Grading & Base Manual, Fig. 6-9 5-692.222 (English)

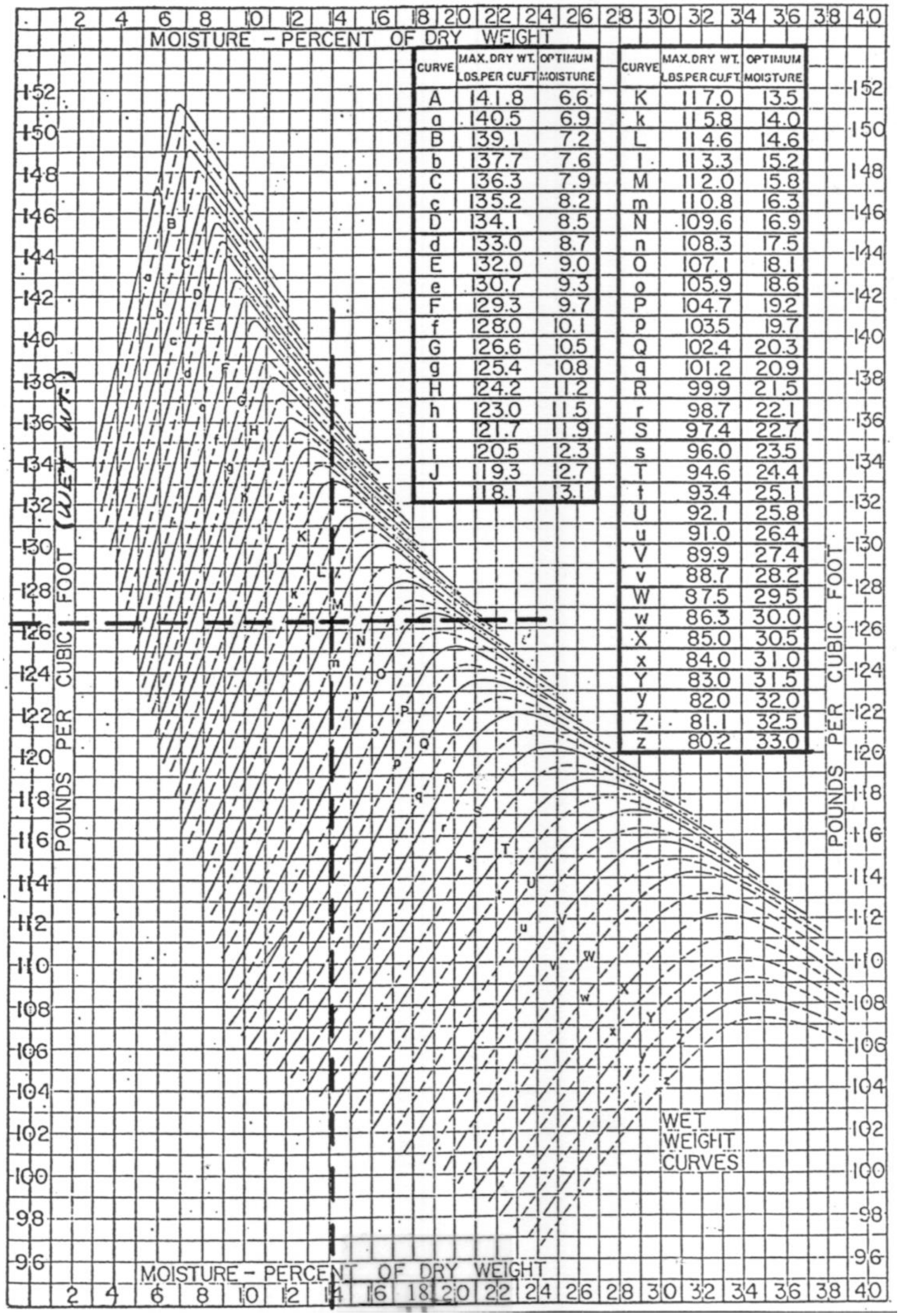
Fig. 9 5-692.222E



Moisture - Density Relationship, Curve G & B Manual

	1	2	3	4	5	6	7	8
A - Wt. Wet Soil + Mold	16.44	16.55	16.64	16.64	16.55			
B - Wt. Mold	12.41	12.41	12.41	12.41	12.41			
C - Wt. Wet Soil	4.03	4.14	4.23	4.23	4.14			
D - Wet Density	120.9	124.2	126.9	126.9	124.2			
E - Wt. Wet Soil + Pan	385.6	408.1	378.1	383.8	381.2			
F - Wt. Dry Soil + Pan	350.2	367.1	336.8	339.2	333.8			
G - Wt. Moisture	35.4	41.0	41.3	44.6	47.4			
H - Wt. Pan	93.8	94.1	93.6	94.2	93.4			
I - Wt. Dry Soil	256.4	273.0	243.2	245.0	240.4			
K - % Moisture - Dry Wt.	13.8	15.0	17.0	18.2	19.7			
L - Dry Density	106.2	108.0	108.5	107.4	103.8			

Fig. 10 5-692.222E



CURVE	MAX. DRY WT. LBS. PER CU. FT.	OPTIMUM MOISTURE
A	141.8	6.6
a	140.5	6.9
B	139.1	7.2
b	137.7	7.6
C	136.3	7.9
c	135.2	8.2
D	134.1	8.5
d	133.0	8.7
E	132.0	9.0
e	130.7	9.3
F	129.3	9.7
f	128.0	10.1
G	126.6	10.5
g	125.4	10.8
H	124.2	11.2
h	123.0	11.5
I	121.7	11.9
i	120.5	12.3
J	119.3	12.7
	118.1	13.1

CURVE	MAX. DRY WT. LBS. PER CU. FT.	OPTIMUM MOISTURE
K	117.0	13.5
k	115.8	14.0
L	114.6	14.6
l	113.3	15.2
M	112.0	15.8
m	110.8	16.3
N	109.6	16.9
n	108.3	17.5
O	107.1	18.1
o	105.9	18.6
P	104.7	19.2
p	103.5	19.7
Q	102.4	20.3
q	101.2	20.9
R	99.9	21.5
r	98.7	22.1
S	97.4	22.7
s	96.0	23.5
T	94.6	24.4
t	93.4	25.1
U	92.1	25.8
u	91.0	26.4
V	89.9	27.4
v	88.7	28.2
W	87.5	29.5
w	86.3	30.0
X	85.0	30.5
x	84.0	31.0
Y	83.0	31.5
y	82.0	32.0
Z	81.1	32.5
z	80.2	33.0

Fig. 11 5-692.222E

5-692.231 CALIBRATION OF SAND CONE AND RING

A. Procedure for Calibration:

Step 1. Place the ring on a piece of paper on a level, solid, vibration free table or bench.

Step 2. Put about 2500 grams of the sand, to be used in the field density test, in the two liter (quart) jar and attach the sand cone device.

Step 3. Weigh the jar, sand and sand cone and record to the nearest gram.

Step 4. Close the valve in the sand cone and invert the jar and cone over the ring.

> **Note:** Make match marks on the funnel and ring so that each time the sand cone is used it may be placed in exactly the same position on the ring.

Step 5. Carefully open the valve so that the sand flows freely into the ring and funnel.

Step 6. When the sand stops flowing, close the valve sharply and remove the jar and sand cone.

Step 7. Weigh the jar, sand cone and sand remaining in the jar and subtract this weight from the weight of the jar, sand and sand cone before filling the ring and funnel. This difference is the weight of sand required to fill the ring and funnel.

Step 8. Repeat Steps 1 through 7 at least three times and calculate the average weight of the sand in grams required to fill the ring and funnel. Round off the average weight to the nearest gram and record. The weight of the sand in the funnel and ring should not vary more than 5 grams from the other trials.

Example:

	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**
Wt. of jar, cone & sand before (g)	**3390**	**3388**	**3384**	**3393**
Wt. of jar, cone & sand after (g)	**2758**	**2761**	**2753**	**2763**
Wt. of sand in funnel & ring (g)	**632**	**627**	**631**	**630**

Average wt. of sand =

$$\frac{632 + 627 + 631 + 630}{4} = 630 \text{ g.}$$

5-692.232 CALIBRATION OF STANDARD SAND

A. Calibrate the sand; that is determine the unit weight of the sand (kg/m^3) [$lbs./ft^3$] to be used in the field density test. The unit weight of each new sack of sand should be determined. Used sand may be resieved and a new unit weight determined. The unit weight of the sand will change if the sand is allowed to become wet or if the gradation of the sand changes. Always protect the sand from contamination. The unit weight of the sand can be determined by using a moisture-density mold of known volume or by comparison of the weight of the sand to an equal volume of water.

B. Procedures For Calibrating Standard Sand:
The Density Cone and Ring are first calibrated using the standard Mn/DOT procedures.

1. Field Method No. 1

Step 1. Weigh the moisture-density mold to the nearest gram (0.01 lb.) and record. Do not include the weight of the collar.

Step 2. Center the mold on a piece of paper placed on a level, solid, vibration free table or bench.

Step 3. Put about 2500 grams of the sand to be calibrated in the two liter jar and attach the sand cone.

Step 4. Close the valve in the sand cone and invert the jar and sand cone over the mold.

Step 5. Carefully open the valve so that the sand flows freely into the mold.

Step 6. When the sand stops flowing, close the valve sharply and remove the jar and cone. Avoid jarring or vibrating the mold.

Step 7. Carefully strike off the excess sand level with the top of the mold with a straight edge.

Step 8. Tap the mold sharply and brush the loose sand off the outside surface of the mold.

Step 9. Weigh the mold and sand to the nearest gram (0.01 lb.) and record.

Step 10. Repeat Steps 2 thru 9 at least three times. The weight of the mold and sand should not vary more than 25 grams (0.05 lb.).

Step 11. Subtract the weight of the mold (Step 1) from the weight of mold and sand to determine the weight of the sand in the mold.

Step 12. Calculate and record the unit weight (kg per m^3) [lb. per cu. ft.] of the sand by dividing the average weight (kg or lb.) of sand in the mold by the volume of the mold (1/1059.43 m^3) [1/30 cu. ft.].

Metric Example:

	Trial 1	Trial 2	Trial 3	Trial 4
Wt. of mold + sand (kg)	**7.093**	**7.123**	**7.085**	**7.104**
Wt. of mold (kg)	**5.620**	**5.620**	**5.620**	**5.620**
Wt. of sand in Mold (kg)	**1.473**	**1.503**	**1.465**	**1.484**

Average weight of sand in mold =

$$\frac{1.473 + 1.465 + 1.484}{3} = 1.474 \text{ kg}$$

Note: Trial 2 was not used because it varied more than 25 grams from at least one other.

Unit weight of sand =

$$\frac{1.474}{1/1059.43} = 1.474 \times 1059.43 = 1562 \text{ kg per } m^3$$

English Example:

	Trial 1	Trial 2	Trial 3	Trial 4
Wt. of mold + sand (lb.)	**15.63**	**15.72**	**15.65**	**15.61**
Wt. of mold (lb.)	**12.40**	**12.40**	**12.40**	**12.40**
Wt. of sand in Mold (lb.)	**3.23**	**3.32**	**3.25**	**3.21**

Average wt. of sand in mold =

$$\frac{3.23 + 3.25 + 3.21}{3} = 3.23 \text{ lb.}$$

Note: Trial 2 was not used because it varied more than 0.05 from at least one other.

Unit Weight of sand =

$$\frac{3.23}{1/30} = 3.23 \text{ x } 30 = 96.9 \text{ lbs. per cu. ft.}$$

2. Field Method No. 2

Step 1. The density bottle is filled with a known weight of Standard Sand, usually about 2500 grams.

Step 2. On a clean, level surface place a Proctor Mold (1/1060 m^3) [1/30 cu. ft.] with it's collar removed.

Step 3. Place the Density Ring on the top edge of the Proctor Mold, being careful to line up the inside edge of the ring with the inside of the mold.

Step 4. Place the Density Cone, with bottle and sand, on the Density Ring. Using the same method as calibrating Cone and Ring.

Step 5. Carefully open the valve on the cone. When the sand stops flowing, close the valve.

Step 6. Weigh the remaining sand in the bottle and record to the nearest gram.

Step 7. Repeat Steps 1 through 6 at least three times. The weight of the sand should not vary more than 5 grams.

Example:

	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**
Final wt. of sand In bottle (g)	**548**	**550**	**561**	**552**

Average weight of sand =

$$\frac{548 + 550 + 552}{3} = 550g.$$

Note: Trial 3 was not used because it varied more than 5 grams from at least one other.

Step 8. Subtract the average weight of sand remaining in the bottle and the weight of sand in cone and ring from the original weight of sand to determine the weight of sand in the mold.

> **Note:** In order to do this procedure, you have to calibrate the Sand Cone and Ring first.

Step 9. Calculate and record the kg (lb.) of sand in mold by dividing the average weight (g) of sand in mold by 1000 g/kg (453.6 gm/lb.).

Step 10. Calculate and record the unit weight (kg per m^3) [lbs. per ft. ^{3}]of sand by multiplying the weight (kg) [lbs.] of sand in mold by 1059.43 (30).

Metric Example: Calculate as follows:
Original wt. of sand = 2500.0 grams = A
Average final wt. of sand = 550.0 grams = B
Wt. of sand in cone & ring = 450.0 grams = C
A - B - C = D
Grams of sand in mold = 1500.0 grams = D
D / 1000 = E
kg of sand in mold = 1.500 kg = E
E x 1059.43 = F
kg/m^3 of sand = 1589 kg/m^3 = F

English Example: Calculate as follows:
Original wt. of sand = 2500.0 grams = A
Average final wt. of sand = 550.0 grams = B
Wt. of sand in cone & ring = 450.0 grams = C
A - B - C = D
Grams of sand in mold = 1500.0 grams = D
D / 453.6 (gms./lb.) = E
1500/453.6 = 3.307 = E
lbs. of sand in mold = 3.307 = E
E x 30 = 99.2 lbs./cu. ft. = F

5-692.245 MOISTURE TEST

A. The moisture test is a method of determining the moisture content of soils and aggregates by means of either drying the sample or by means of a calcium carbide gas pressure (CCGP) moisture meter. Moisture tests are taken to determine if the moisture content, expressed as a percentage of the dry weight, is in compliance with the placement and compaction requirements of the specifications. The moisture content should be determined at the time compaction of the material starts. Moisture requirements should be met and maintained for each layer of embankment before the next layer is deposited. If the moisture content of embankment, particularly in plastic soils is not properly tested and controlled, the subgrade will likely become unstable under the operation of construction equipment during base and pavement construction. The method used to determine the moisture content depends on the type of soil aggregate as follows:

1. The burner method may be used to determine the moisture content of any grading, subgrade, base or shoulder material. Minor variations of the procedure are necessary for reliable results when testing materials that have been treated, such as with bituminous. (See 5-692.216.)
2. The calcium carbide gas pressure (CCGP) method may be used to determine the moisture content of untreated grading soils, subbase and base aggregate except those granular materials having particles large enough to affect the accuracy of the test. Either a 26 gram soil sample size “Speedy” or 200 gram soil sample size “Super Speedy” moisture meter is used.

   The 26 gram “Speedy” meter is to be used for non–granular soils—in general, no appreciable amount retained on the 4.75 mm (No. 4) sieve. The 200 gram “Super Speedy” meter is to be used for granular soils and aggregate base with particle size not to exceed 50 mm (2”). The CCGP method is as reliable and accurate as the burner method in these cases.

   Note: Use Form Mn/DOT TP-21850, Relative Moisture Test, to record field moisture determinations (See Fig. 1 5-692.253M or E.)

B. Burner Method
   1. Equipment
      a. A balance of at least 2500 gram capacity sensitive to 0.1 gram and with minor graduations on the indicator for 0.1 gram.
      b. Stove, oven, or other suitable equipment for drying moisture content samples.
      c. Frying pan or any suitable container for drying and weighing samples.
   2. Procedure
      Step 1. Select a representative soil sample. The larger the sample used, the more accurate the test results will be. The minimum size sample should range from 100 grams for fine grained soils to 1000 grams for 50 mm (2”) maximum particle size. At least 500 grams of base aggregate should be used.

Step 2. Weigh the pan or container to be used to the nearest gram and record the weight.

Step 3. Weigh the wet sample and container to the nearest gram and record the weight.

Step 4. Dry the sample to a constant weight by weighing the sample after it appears dry, reheat it for a short time and weigh again. Continue drying and weighing the sample until the weight remains constant.
Note: To prevent burning or warping of the balance, the sample should be allowed to cool or a heat pad should be used to protect the balance.

Step 5. Weigh the sample and container to the nearest gram and record the weight.

Step 6. Determine the weight of moisture in the sample by subtracting the weight of the dry sample and pan from the weight of the wet sample and pan.

Step 7. Determine the weight of the dry material by subtracting the weight of the pan from the weight of the dry material and pan.

Step 8. Calculate the percent moisture of the dry weight by dividing the weight of the moisture by the weight of the dry material and then multiply by 100.

Example:

Wet wt. of sample and pan = 327 g
Dry wt. of sample and pan = 305 g
Weight of pan = 79 g
Wt. of moisture = 327 – 305 = 22 g
Wt. of dry material = 305 – 79 = 226 g

% moisture, dry wt. =

$$\frac{22}{226} \times 100 = 9.7\%$$

Note: The percent moisture of the wet weight is calculated by dividing the weight of the moisture by the weight of the wet material.

C. CCGP Method using the 26 gram "Speedy" Moisture Meter.

1. Equipment

The "Speedy" moisture meter is furnished as a kit containing the CCGP meter, tared scale, two 31 mm (1 1/4") steel balls, cleaning brush and cloth, and scoop for measuring calcium carbide reagent.

Calcium carbide reagent is available in one pound cans. The calcium carbide to be used should be "fresh" and, therefore should not be more than 2–3 years old even though the container has never been opened. After a container has been opened and then resealed properly, its full strength will probably dissipate within two months to a point at which it will not produce accurate test results and should be discarded.

> **Caution:** Do not attempt to use the "Speedy" unless the kit is complete. Calcium carbide and water produces a dangerous, flammable gas. Keep the reagent can closed tightly, avoid breathing the fumes and use only in a well ventilated area. Point the opening of the tester away while removing the cap. Tape the metal handle of the cleaning brush; otherwise, when the metal handle comes in contact with the chamber a spark could ignite gas trapped in the chamber. Keep the kit clean; do not allow the instrument to be mishandled.

2. Transporting Calcium Carbide
(Speedy Moisture Tester Reagent)

This material may be transported under an exemption to the strict DOT shipping requirements for hazardous materials, **if all the following procedures are strictly followed:**

A. You are carrying no more than one pound or a ½ kilogram in the original manufacturer's container.
B. This container is stored in a secured durable box.
C. The durable box is clearly labeled on all sides with:
    1. Calcium Carbide, 4, 3
    2. UN 1402, P G II
    3. Limited Quantity

    (See Fig. 10 5-592.245)

D. The shipping manifest is within reach of the driver at all times.
E. The shipping manifest must include the following information.
    1. Calcium Carbide, 4, 3
    2. UN1402, Packing Group PG II
    3. Limited Quantity
    4. The weight or volume of material being carried
    5. The Emergency Response telephone number

Note: Citations and penalties for failure to comply with DOT shipping requirements for hazardous mateials are the sole responsibility of the motor vehicle drivers.

(See Fig. 11 5-692.245)

3. Procedure

Step 1. Set the "Speedy" carrying case on level ground or a solid, level bench. The tared balance must be level to be reliable.

Step 2. Select a representative soil sample and weigh out an exact amount on the tared balance. The tared balance weighs either a 26 or 13 gram sample. The pressure gage indicates up to 20 percent moisture in a 26 gram sample or 40 percent moisture in a 13 gram sample. If the moisture is expected to be five to 20 percent, use a 26 gram sample; if 20 to 40 percent, a 13 gram sample; and, if over 40 percent, use the burner method. If the soil contains less than five percent moisture, use two or more 26 gram samples.

Step 3. Calculate and record the Sample Size Factor using the following formula:

Sample Size Factor =

$$\frac{26}{\text{weight of sample used}}$$

Step 4. Place the weighed soil sample in the cap of the meter. Be certain the cap is clean.

Step 5. Place three full scoops of reagent and the two steel balls in the body of the meter.

Step 6. Hold the body of the meter in an approximately horizontal position, insert the cap into the body, and seal the unit by positioning and tightening the clamp. The calcium carbide should not come in contact with the soil until a complete seal is made. (See Figure 1)

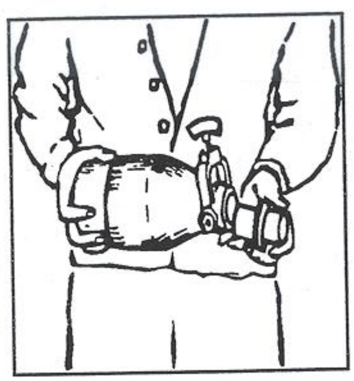


Figure 1

Step 7. Tilt the meter so that the sample falls into the body and begins mixing with the reagent.

Step 8. Return the Speedy to the horizontal position. Shake the tester to pulverize any soil lumps and to cause mixing so that the reaction between the calcium carbide and all free moisture is complete. The meter should be shaken with a rotating motion so that the steel balls will not damage the gauge and soil particles will not become imbedded in the orifice leading to the pressure diaphragm. Do not allow the balls to hit the gauge end of the meter. Attempt to roll the balls rather than rattle them. Up to four minutes of shaking may be required on heavy clay type soils. Allow time for the dissipation of heat generated by the chemical reaction. (See Figure 2)

Figure 2

Step 9. Hold the meter horizontal at eye level with the dial facing you. (See Figure 3) When the needle comes to rest, read the dial to the nearest 0.1 percent and record the dial reading.

Figure 3

Step 10. Calculate and record the percent moisture of the wet weight by multiplying the dial reading by the sample size factor.

Step 11. Determine and record the percent moisture by dry weight by using Table A 5-692.245 or the following formula:

$$\%\text{ moisture, dry wt.} = \frac{\%\text{ moisture, wet wt.}}{1 - \left(\dfrac{\%\text{ moisture, wet wt.}}{100}\right)}$$

Example:

% moisture, wet wt. = 12.8%

% moisture, dry wt. =

$$\frac{12.8}{1 - \dfrac{12.8}{100}} = \frac{12.8}{0.872} = 14.7\%$$

Step 12. Point the opening away, slowly release the pressure and remove the cap.

Step 13. Dump the material from the meter and examine. The soil must be completely pulverized. Lumps indicate an inaccurate test that must be re-run, increasing the shaking time.

Step 14. Brush out the body of the meter. Wipe out the cap and clean off the two steel balls with the special cleaning rag.

Note: Keep the Speedy kit clean at all times. Never leave the kit out in the rain or allow anyone to mishandle any part of it.

D. CCGP method using the 200 gram “Super speedy” moisture meter.

1. Equipment

The “Super Speedy” 200 kit consists of the moisture meter, counterpoised balance, measuring scoop, brushes, two steel balls, a 200 gram weight and 100 gram half sample weight, heat shield, two gauges and gauge removing tool. One gauge for determining the moisture content by wet weight is calibrated from zero to eleven percent. The other gauge is for determining the moisture content by dry weight and is calibrated from zero to 12 percent. To change gauges, use the special tool supplied. The tool is designed to grip the three screws on the outer casing of the gauge. To remove the gauge turn in a counter-clockwise direction. To replace the gauge, turn in a clockwise direction.

Caution: See caution paragraph for “Speedy” moisture meter.
(See 5-692.215.C.1)

2. Transporting Calcium Carbide
(Speedy Moisture Tester Reagent)

This material may be transported under an exemption to the strict DOT shipping requirements for hazardous materials, **if all the following procedures are strictly followed:**

A. You are carrying no more than one pound or a ½ kilogram in the original manufacturer's container.
B. This container is stored in a secured durable box.
C. The durable box is clearly labeled on all sides with:
    1. Calcium Carbide, 4.3
    2. UN1402, P G II
    3. Limited Quantity

(See Fig. 10, 5-592.245)

D. The shipping manifest is within reach of the driver at all times.
E. The shipping manifest must include the following information.
    1. Calcium Carbide, 4, 3
    2. UN1402, Packing Group PG II
    3. Limited Quantity
    4. The weight or volume of material being carried
    5. The Emergency Response telephone number

Note: Citations and penalties for failure to comply with DOT shipping requirements for hazardous mateials are the sole responsibility of the motor vehicle drivers.

(See Fig. 11, 5-692.245)

3. Procedure
Step 1. Set the "Super Speedy" carrying case on level ground or a solid, level bench. The tared balance must be level to be reliable.

Step 2. Select a representative sample and weigh a 200 gram sample on the balance provided. If the moisture content is likely to exceed the maximum gauge reading, use a half sample (100 g) and the wet weight gauge. The half sample method cannot be used with the dry weight gauge.

Step 3. Calculate and record the sample size factor using the following formula:

Sample size factor =

$$\frac{200}{\text{weight of sample used}}$$

Step. 4 Place the weighed sample in the cap of the meter. (See Figure 4)

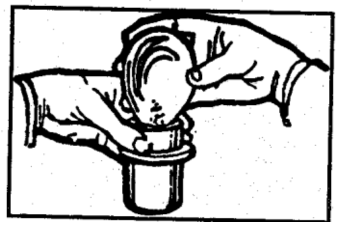


Figure 4

Step 5. Place six full measures of regent in the body of the "Super Speedy" (See Figure 5). Place the two steel pulverizing balls in the body.

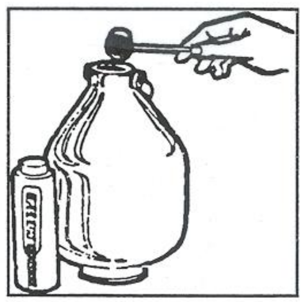


Figure 5

Step 6. Hold the "Super Speedy" in an approximately horizontal position, insert the cap into the body and seal the unit by tightening the clamp. Care must be taken to prevent the reagent from coming in contact with the sample before the seal is complete. (See Figure 6)

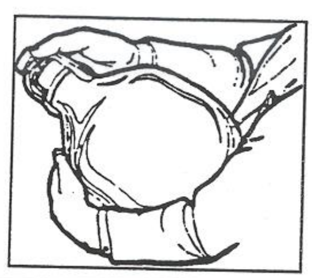


Figure 6

Step 7. With the dial downward, shake the unit round and round for approximately five seconds. Hold or stand the "Super Speedy" in a vertical position for one minute. (See Figure 7)

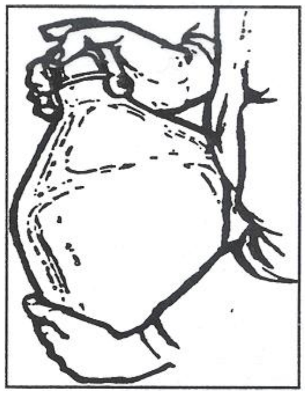


Figure 7

Step 8. Repeat Step 7, shake once more and turn the unit into a horizontal position at eye level with the dial facing you. When the needle comes to rest, read the dial to the nearest 0.1 percent and record the dial reading. (See Figure 8)

Figure 8

Step 9. Calculate and record the percent moisture by multiplying the dial reading by the sample size factor.

If the dry weight gauge was used, record the percent moisture of the dry weight. If the wet weight gauge was used, record the percent moisture of wet weight and determine the percent moisture of dry weight by using Table A 5-692.250 or the following formula:

$$\text{\% moisture, wet wt.} = \frac{\text{\% moisture, wet wt.}}{1 - \left(\frac{\text{\% moisture, wet wt.}}{100}\right)}$$

Step 10. Point the opening away, slowly release the pressure and remove the cap. (See Figure 9)

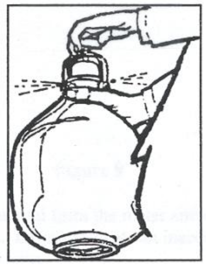


Figure 9

Step 11. Dump the material from the meter and examine. The soil must be completely pulverized. Lumps indicate an inaccurate test that must be rerun, increasing the shaking time.

Step 12. Brush out the body of the meter. Wipe out the cap and clean off the two steel balls with the special cleaning rag.

> **Note:** Keep the Speedy kit clean at all times. Never leave the kit out in the rain or allow anyone to mishandle any part of it.

Figure 10 5-692.245

MINNESOTA DEPARTMENT OF TRANSPORTATION

HAZARDOUS MATERIAL SHIPPING DOCUMENT

Date: June 15, 2002

Shipped From: Office of Materials and Road Research **Shipped To:** Trunk Highway Construction Projects

1400 Gervais Ave., Maplewood, MN 55109 Minnesota Trunk Highways

Equipment: Speedy Moisture Test Reagent **Unit:** One (1) pound Can

Description & Classification	Hazard Class	Identification Number (If applicable)	Packing Group (If applicable)	Quantity	Size	Total
Calcium Carbide, Class 4.3 UN 1402 (LIMITED QUANTITY)	4.3	UN 1402	Packing Group II	Limited Quantity	1 lb.	1 lb.

Figure 11 5-692-245

CONVERSION TABLE – PERCENT MOISTURE

WET	DRY	WET	DRY	WET	DRY	WET	DRY
0.0	0.0	7.0	7.5	14.0	16.3	21.0	26.6
0.1	0.1	7.1	7.6	14.1	16.4	21.1	26.7
0.2	0.2	7.2	7.8	14.2	16.6	21.2	26.9
0.3	0.3	7.3	7.9	14.3	16.7	21.3	27.1
0.4	0.4	7.4	8.0	14.4	16.8	21.4	27.2
0.5	0.5	7.5	8.1	14.5	17.0	21.5	27.4
0.6	0.6	7.6	8.2	14.6	17.1	21.6	27.6
0.7	0.7	7.7	8.3	14.7	17.2	21.7	27.7
0.8	0.8	7.8	8.5	14.8	17.4	21.8	27.9
0.9	0.9	7.9	8.6	14.9	17.5	21.9	28.0
1.0	1.0	8.0	8.7	15.0	17.6	22.0	28.2
1.1	1.1	8.1	8.8	15.1	17.8	22.1	28.4
1.2	1.2	8.2	8.9	15.2	17.9	22.2	28.5
1.3	1.3	8.3	9.1	15.3	18.1	22.3	28.7
1.4	1.4	8.4	9.2	15.4	18.2	22.4	28.9
1.5	1.5	8.5	9.3	15.5	18.3	22.5	29.0
1.6	1.6	8.6	9.4	15.6	18.5	22.6	29.2
1.7	1.7	8.7	9.5	15.7	18.6	22.7	29.4
1.8	1.8	8.8	9.6	15.8	18.8	22.8	29.5
1.9	1.9	8.9	9.8	15.9	18.9	22.9	29.7
2.0	2.0	9.0	9.9	16.0	19.0	23.0	29.9
2.1	2.1	9.1	10.0	16.1	19.2	23.1	30.0
2.2	2.2	9.2	10.1	16.2	19.3	23.2	30.2
2.3	2.4	9.3	10.3	16.3	19.4	23.3	30.4
2.4	2.5	9.4	10.4	16.4	19.6	23.4	30.5
2.5	2.6	9.5	10.5	16.5	19.8	23.5	30.7
2.6	2.7	9.6	10.6	16.6	19.9	23.6	30.9
2.7	2.8	9.7	10.7	16.7	20.0	23.7	31.1
2.8	2.9	9.8	10.9	16.8	20.2	23.8	31.2
2.9	3.0	9.9	11.0	16.9	20.3	23.9	31.4
3.0	3.1	10.0	11.1	17.0	20.5	24.0	31.6
3.1	3.2	10.1	11.2	17.1	20.6	24.1	31.8
3.2	3.3	10.2	11.4	17.2	20.8	24.2	31.9
3.3	3.4	10.3	11.5	17.3	20.9	24.3	32.1
3.4	3.5	10.4	11.6	17.4	21.1	24.4	32.3
3.5	3.6	10.5	11.7	17.5	21.2	24.5	32.5
3.6	3.7	10.6	11.9	17.6	21.4	24.6	32.6
3.7	3.8	10.7	12.0	17.7	21.5	24.7	32.8
3.8	4.0	10.8	12.1	17.8	21.7	24.8	33.0
3.9	4.1	10.9	12.2	17.9	21.8	24.9	33.2
4.0	4.2	11.0	12.4	18.0	22.0	25.0	33.3
4.1	4.3	11.1	12.5	18.1	22.1	25.1	33.5
4.2	4.4	11.2	12.6	18.2	22.2	25.2	33.7
4.3	4.5	11.3	12.7	18.3	22.4	25.3	33.9
4.4	4.6	11.4	12.9	18.4	22.5	25.4	34.0
4.5	4.7	11.5	13.0	18.5	22.7	25.5	34.2
4.6	4.8	11.6	13.1	18.6	22.9	25.6	34.4
4.7	4.9	11.7	13.3	18.7	23.0	25.7	34.6
4.8	5.0	11.8	13.4	18.8	23.2	25.8	34.8
4.9	5.2	11.9	13.2	18.9	23.3	25.9	35.0
5.0	5.3	12.0	13.6	19.0	23.5	26.0	35.1
5.1	5.4	12.1	13.8	19.1	23.6	26.1	35.3
5.2	5.5	12.2	13.9	19.2	23.8	26.2	35.5
5.3	5.6	12.3	14.0	19.3	23.9	26.3	35.7
5.4	5.7	12.4	14.2	19.4	24.1	26.4	35.9
5.5	5.8	12.5	14.3	19.5	24.2	26.5	36.1
5.6	5.9	12.6	14.4	19.6	24.4	26.6	36.2
5.7	6.0	12.7	14.5	19.7	24.5	26.7	36.4
5.8	6.2	12.8	14.7	19.8	24.7	26.8	36.6
5.9	6.3	12.9	14.8	19.9	24.8	26.9	36.8
6.0	6.4	13.0	14.9	20.0	25.0	27.0	37.0
6.1	6.5	13.1	15.1	20.1	25.2	27.1	37.2
6.2	6.6	13.2	15.2	20.2	25.3	27.2	37.4
6.3	6.7	13.3	15.3	20.3	25.5	27.3	37.6
6.4	6.8	13.4	15.5	20.4	25.6	27.4	37.7
6.5	7.0	13.5	15.6	20.5	25.8	27.5	37.9
6.6	7.1	13.6	15.7	20.6	25.9	27.6	38.1
6.7	7.2	13.7	15.9	20.7	26.1	27.7	38.3
6.8	7.3	13.8	16.0	20.8	26.3	27.8	38.5
6.9	7.4	13.9	16.1	20.9	26.4	27.9	38.8

5-692.246 FIELD DENSITY TEST BY THE SAND CONE METHOD

5-692.247 SAMPLING AND INSPECTION

A. Density tests are taken to determine whether embankment or base materials have been compacted to the specified density. Tests should be made immediately after compaction to permit corrective work, before drying and hardening occurs, in sections where the specified density has not been attained. It is also easier, faster and more accurate to perform tests on a moist, newly compacted surface than on one that has become hard, dry and rough.

B. Before selecting locations for the density test, examine the section to be tested for uniformity. Where it appears that there is a lack of stability or compaction, the density should be determined. In sections where there is apparent uniformity of materials and compaction, such as for granular soils or aggregate base, select locations for density determinations at random: but avoid traffic wheel tracks, areas where segregation of materials occur, and locations having pocketed soil conditions.

C. When embankment or base materials being tested contain stones larger than 25 mm (1”), care must be exercised to avoid areas of marked deviation from average conditions. If large stones are encountered in digging the hole, select a new location.

D. At all test locations, the material should be closely examined to determine whether a moisture-density curve has been developed from the same class of material. If none of the available moisture - density curves are representative of the material being tested, additional material should be obtained from determination of the moisture-density relations. (See 5-692.222.)

5-692.248 FIELD DENSITY TEST PROCEDURE

A. This field density test is a method of determining the in-place density of grading soils or aggregate base, subbase and aggregate surfacing and is a modification of AASHTO T 191. The test consists of digging a hole about 100 mm (4”) in diameter and as deep as necessary to test the layer in-place. All of the material is carefully removed and weighed. The volume of the hole is determined by filling the hole with sand of known unit weight. The moisture content is determined and the dry density of the material is calculated.

B. The following apparatus is necessary:
1. Two liter(quart) mason jar with sand cone and valve attachment.
2. Ring with a 100 mm (4”) diameter center hole, two nails and hammer.
3. Sample containers, such as tin cans with lids, for retaining the density sample.
4. Small pick, chisels and spoons for digging the test hole. Spatula and small brush.
5. A balance of at least 2500 grams capacity sensitive to 0.1 gram and with minor gradations on the indicator for 0.1 gram.
6. Speedy moisture meter, stove or oven and suitable containers for drying and weighing moisture content samples.

7. A moisture-density mold with a volume of approximately 1/1060 m^3 (1/30 cu. ft.) (See 5-692.222.)
8. A platform scale with a minimum 14 kg (30 lb.) capacity sensitive to one gram and with minor gradations on the indicator of one gram (0.01 lb.).
9. Supply of standard sand. The sand used to determine the volume of the hole is a silica sand graded to pass a 850 µm (No. 20) sieve and be retained on a 600 µm (No. 30) sieve. The sand is usually supplied in 24 kg (50 lb.) sacks. If standard sand is not available, local sand may be used if it is free flowing, washed, dried and sieved through a 850 µm (No. 20) and 600 µm (No. 30) sieve. Use the sand retained on the 600 µmNo. 30) sieve.

Note: Use Form Mn/DOT TP-2140, Relative Density test, to record field density determinations. (See Fig. 1 5-692.251)

C. Determine the density of the soil in place.

Step 1. Select the location of the test (see 5-692.247). Remove any loose material.

Step 2. Smooth and level the surface of the area until the ring can be evenly seated. Secure with nails driven through the pre-drilled holes on the opposite sides of the ring into the soil.

Step 3. Dig the test hole the size of the inside diameter of the ring being very careful to avoid disturbing the soil that will bound the hole. Granular soils require extreme care. Cut the sides of the hole vertical and smooth out rough spots that may develop when small stones are loosened. If stones larger than 50 mm (2”) are loosened, remove them but do not include them with the finer material in the sample container. Dig the hole as deep as necessary to test the layer compacted. Place all loosened soil in a clean container being careful to avoid losing any material.

Note 1: Density tests on **grading construction** usually represents layers 200 mm (8”) or 300 mm (12”) in thickness (loose measurement). The test hole for grading construction should be at least 115 mm (4 1/2”) deep and yield from 1200 grams of dry material for fine grained soils to 1800 grams for gravelly soils. The standard sand cone density testing device with an approximate cone of 115 mm (4 1/2”) diameter is recommended.

Note 2: Density tests on **base aggregate construction** usually represent 75 mm (3”) or 150 mm (6”) compacted lifts. When the compacted lift is between 75 mm (3”) and 150 mm (6”), the test hole should be at least 60 mm (2 1/2”) in depth and yield about 2000 grams of dry material. The minimum lift that can be accurately tested is 50 mm (2”) in depth. The 50 mm (2”) test hole should yield a minimum of 1650 grams. The larger sand cone testing device with an approximate cone of 165 mm (6 1/2”) diameter is recommended.

Step 4. Weigh and record a quantity of sand plus container. Place the sand in the two liter (quart) jar and attach the sand cone.

> **Note:** The amount of sand needed depends on the size of the test hole. When the standard 115 mm (4 1/2”) diameter sand cone test device is used, 2200 grams is usually enough for a 75 mm (3”) to 115 mm (4 1/2”) deep. When the larger 165 mm (6 1/2”) diameter sand cone test device is used, usually 2500 grams is enough for aggregate test.

Step 5. Invert the jar and sand cone and place it on the ring. Use the match marks on the ring and funnel to make sure they are in the same position as when the device was calibrated.

> **Note:** Do not allow construction equipment to operate within 10 meters (30’) of test site while testing is in progress.

Step 6. Open the valve and allow the sand to fill the hole and the sand cone.

> **Note:** If stones larger than 50 mm (2”) were removed from the hole in Step 3, open the valve and let a small amount of sand flow into the hole; close the valve, remove the sand cone and place the rocks on the sand bedding in the hole; replace the jar and sand cone, reopen the valve and complete Step 6.

Step 7. When the sand stops flowing, close the valve and remove the jar and sand cone.

Step 8. Weigh and record the sand remaining plus container.

Step 9. Weigh the wet material removed from the hole.

Step 10. Determine the moisture content of a representative portion of the material from the hole by the burner method or speedy moisture meter. The procedure for determining the moisture content is contained in 5-692.245. The moisture content expressed as a percent of the wet weight must be used if the procedure outlined on Form Mn/DOT TP 2140 is used. Record the percent moisture.

D. Calculations

Step 1. Calculate and record the weight of the sand used in the test by subtracting the weight of the container and sand remaining after performing the test (Steps 5 thru 8, above) from the weight of the container and sand before performing the test (Step 4).

Step 2. Calculate and record the weight of the sand required to fill the hole by subtracting the weight of the sand required to fill the ring and the funnel from the weight of the sand used in the test (Step 1, above).

Step 3. Determine the dry weight of the material by calculating the weight of the moisture and subtracting it from the wet weight of the material from the hole.

Example:

Wet wt. of material = 1368 g
Moisture content = 7.48%

$$\text{Wt. of moisture} = \text{wet wt. x } \frac{\%\text{ moisture}}{100} = 1368 \text{ x } 0.0748 = 102 \text{ g}$$

Dry wt. = wet wt. - wt. of moisture = 1368 - 102 = 1266 g

Note: An alternate method of obtaining the dry weight is to dry all the material removed from the test hole (minus 50 mm size) [2”]and weigh it to the nearest gram. Record this weight as the dry weight of the material from the hole.

Step 4. Calculate the dry density of the in-place material using the formula:

Dry Density, kg/m^3 =

$$\frac{\text{dry wt. of material (g)}}{\text{wt. of sand inside hole (g)}} \text{ x unit of sand inside hole (kg/m}^{3)}$$

Example:

Dry wt. of material removed from hole = 1266 g
Wt. of sand required to fill hole = 958 g
Unit wt. of standard sand (from calibration) = 1554 kg/m^3 (Metric)
= 97.1 lb./cu. ft. (English)

$$\text{Metric Dry Density} = \frac{1266}{958} \text{ x } 1554 = 2054 \text{ kg/m}^3$$

$$\text{English Dry Density} = \frac{1266}{958} \text{ x } 97.1 = 128.3$$

5-692.251M RELATIVE DENSITY

A. Relative density is the ratio, in percent, of the field density of in-place embankment, base or subbase aggregate to the maximum density of the material. The field density of the in-place material is determined by the field density test by the sand cone method. (See 5-692.246.) The maximum density is determined by the moisture-density test. (See 5-692.222.)

The relative density of the in-place compacted embankment, base or subbase is compared to the percent density specified to determine if the material has been compacted as required.

B. Relative density is calculated by using the following formula:

$$\text{Relative Density (\%)} = \frac{\text{Field density (kg per m}^3\text{)}}{\text{Maximum density (kg per m}^3\text{)}} \times 100$$

Example:

Field Density (Dry Density = 2091 kg/m^3

Maximum Density = 2050 kg/m^3

$$\text{Relative Density} = \frac{2091}{2050} \times 100 = 102\%$$

See Fig. 1 5-692.251M, Form TP 2140 which conbines the field density test and relative density determination.

TP-02140-03 (4/21/02)

Minnesota Department of Transportation

Office of Materials and Road Research

Page No. 3

Relative Density Test Grading & Base Construction

S. P. No: 1905-28

Test Identification Data					
Date	5-18-01	5-18-01	5-19-01	6-29-01	6-29-01
Test No.	15	16	16A	11	12
Soil Class or 3138 Class	CL	CL	CL	Cl.5	Cl.5
Station	99+000	101+510	101+510	97+250	97+503
Roadway: Position to Center Line	NBL 2 Rt	SBL ℄	SBL ℄	EB 4 Lt	WB 3 Rt
Depth Below Grade	1.0 m	2.2 m	2.2 m	75 mm	150 mm
Volume Determination (sand cone)					
A. Wt. Sand & Container Before	3490	3489	3503	3084	3081
B. Wt. Sand & Container After	1516	1448	1606	1496	1516
C. Wt. Sand in Funnel & Hole A-B	1974	2041	1897	1588	1565
D. Wt. Sand in Funnel (from Calib)	651	651	651	630	630
E. Wt. Sand in in Hole C-D	1323	1390	1246	958	935
Inplace Dry Density Determination (Field Density Test)					
Container No.	A	B	C	1	2
- Burner Method -					
F. Wt. Wet Soil + Pan		866			747
G. Wt. Dry Soil + Pan		756			719
H. Wt Moisture F-G		110			28
J. Wt Pan		208			210
K. Wt. Dry Soil F-J		658			537
- Speedy Method -					
M. Dial Reading	13.7			7.48	
N. Sample Size Factor	1			1	
P. % Moisture - Wet Wt. H/K*100 or M*N	13.7	16.7		7.48	5.21
R. Total Wt. Wet Mat. From Hole	1773	1758		1368	1313
S. Wt.Moist. in Mat. from Hole R x P/100	243	294		102	68
T. Dry Wt.of Mat. from Hole R - S	1530	1464	1382	1266	1245
U. Unit Wt. of Sand kg/m^3	1562	1562	1562	1554	1554
V. Dry Density kg/m^3 T/E x U	1806	1645	1732	2054	2069
Relative Density Determination					
W. Std Maximum Density	1778	1746	1746	2034	2034
Specs.	100	95	95	100	100
Relative Density % V/W x 100	102	94	99	101	102
Curve No.	3	5	5	7	7
Inspector: Sandy Cohen	SC	SC	SC	SC	SC
Project Engineer Pete Loam	See Grading and Base Manual 5-692.251 (M) or 5-692.251 (E)				

Figure 1 5-692.251M

5-692.251E RELATIVE DENSITY

A. Relative density is the ratio, in percent, of the field density of in-place embankment, base or subbase aggregate to the maximum density of the material. The field density of the in-place material is determined by the field density test by the sand cone method. (See 5-692.246.) The maximum density is determined by the moisture-density test. (See 5-692.222.)

The relative density of the in-place compacted embankment, base or subbase is compared to the percent density specified to determine if the material has been compacted as required.

B. Relative density is calculated by using the following formula:

$$\text{Relative Density (\%)} = \frac{\text{Field density (lbs. per ft}^3\text{)}}{\text{Maximum density (lbs. per ft}^3\text{)}} \times 100$$

Example:

Field Density (Dry Density = 118.6 lbs./ft^3

Maximum Density = 116.3 lbs./ft^3

$$\text{Relative Density} = \frac{118.6}{116.3} \times 100 = 102\%$$

See Fig. 1 5-692.251E, Form TP 2140 which conbines the field density test and relative density determination.

TP-02140-03 (4/21/02)

Minnesota Department of Transportation

Office of Materials and Road Research

Page No. 2

Relative Density Test Grading & Base Construction

S. P. No: 1908-23

Test Identification Data					
Date	5-18-01	5-18-01	5-19-01	7-9-01	7-9-01
Test No.	15	16	16A	11	12
Soil Class or 3138 Class	CL	CL	CL	Cl.5	Cl.5
Station	302+00	524+00	524+00	727+00	758+50
Roadway: Position to Center Line	NBL 8' Rt	SBL ℄	SBL ℄	EB 6' Rt	WB ℄
Depth Below Grade	2'	6'	6'	3"	3"
Volume Determination (sand cone)					
A. Wt. Sand & Container Before	3490	3489	3503	3084	3081
B. Wt. Sand & Container After	1516	1448	1606	1496	1516
C. Wt. Sand in Funnel & Hole A-B	1974	2041	1897	1588	1565
D. Wt. Sand in Funnel (from Calib)	651	651	651	630	630
E. Wt. Sand in in Hole C-D	1323	1390	1246	958	935
Inplace Dry Density Determination (Field Density Test)					
Container No.	A	B	C	1	2
- Burner Method -					
F. Wt. Wet Soil + Pan		866			747
G. Wt. Dry Soil + Pan		756			719
H. Wt Moisture F-G		110			28
J. Wt Pan		208			210
K. Wt. Dry Soil F-J		658			537
- Speedy Method -					
M. Dial Reading	13.7			7.48	
N. Sample Size Factor	1			1	
P. % Moisture - Wet Wt. H/K*100 or M*N	13.7	16.7		7.48	5.21
R. Total Wt. Wet Mat. From Hole	1773	1758		1368	1313
S. Wt.Moist. in Mat. from Hole R x P/100	243	294		102	68.4
T. Dry Wt.of Mat. from Hole R - S	1530	1464	1382	1266	1245
U. Unit Wt. of Sand kg/m^3	97.5	97.5	97.5	97.0	97.0
V. Dry Density kg/m^3 T/E x U	112.8	102.7	108.1	128.2	129.2
Relative Density Determination					
W. Std Maximum Density	111.0	109.0	109.0	127.0	127.0
Specs.	100	95	95	100	100
Relative Density % V/W x 100	102	94	99	101	102
Curve No.	3	5	5	7	7
Inspector: Sandy Cohen	SC	SC	SC	SC	SC

Project Engineer Clay Seems

See Grading and Base Manual 5-692.251 (M) or 5-692.251 (E)

Figure 1 5-692.251E

5-692.253M RELATIVE MOISTURE

A. Relative moisture is the ratio, in percent, of the moisture content of an embankment soil, base or subbase aggregate to the optimum moisture of the material. Moisture content of the material is determined by the moisture test. (See 5-692.245.) The optimum moisture is determined by the moisture density test. (See 5-692.222.)

Where the specified density method of compaction is specified or when constructing a control strip, the moisture content of the soil or aggregate is determined at the time the material is being compacted.

The relative moisture is compared to the specified moisture content to determine if moisture content required for compaction of the material is acceptable.

B. Relative moisture is calculated by using the following formula:

$$\text{Relative moisture (\%)} = \frac{\text{Moisture content (\%)}}{\text{Optimum content (\%)}} \times 100$$

Example:

Moisture Content (% of Dry Wt.) = 15.9%
Optimum Moisture (% of Dry Wt.) = 16.6%

$$\text{Relative Moisture} = \frac{15.9}{16.6} = 96\%$$

See Fig. 1 5-692.253M, Form 21850, which combines the moisture test and the relative moisture determination.

5-692.253E RELATIVE MOISTURE

A. Relative moisture is the ratio, in percent, of the moisture content of an embankment soil, base or subbase aggregate to the optimum moisture of the material. Moisture content of the material is determined by the moisture test. (See 5-692.245.) The optimum moisture is determined by the moisture density test. (See 5-692.222.)

Where the specified density method of compaction is specified or when constructing a control strip, the moisture content of the soil or aggregate is determined at the time the material is being compacted.

The relative moisture is compared to the specified moisture content to determine if moisture content required for compaction of the material is acceptable.

B. Relative moisture is calculated by using the following formula:

$$\text{Relative moisture (\%)} = \frac{\text{Moisture content (\%)}}{\text{Optimum content (\%)}} \times 100$$

Example:

Moisture Content (% of Dry Wt.) = 15.9%
Optimum Moisture (% of Dry Wt.) = 16.6%

$$\text{Relative Moisture} = \frac{15.9}{16.6} = 96\%$$

See Fig. 1 5-692.253E, Form 21850, which combines the moisture test and the relative moisture determination.

TP-21850-02 (4/21/02)

Minnesota Department of Transportation

Office of Materials and Road Research

Page No. 10

Relative Moisture Test Grading & Base Construction

S. P. No: 1401-07

Test Identification Data					
Date	6-10-01	6-10-01	6-17-01	6-17-01	
Test No.	33	33A	34	35	
Soil Class or 3138 Class	CL	CL	CL	C	
Station	302+000	301+980	410+615	389+044	
Roadway: Position to Center Line	8 m Rt	3 m Rt	℄	4 m Lt	
Depth Below Grade	700 mm	700 mm	1 m	1.3 m	
Moisture Determination					
Container No.	A	B	A		
- Burner Method -					
A. Wt. Wet Material + Pan	643	615	576		
B. Wt. Dry Material + Pan	581	556	539		
C. Wt Moisture A-B	62	59	37		
D. Wt Pan	192	152	192		
E. Wt. Dry Soil B-D	389	404	347		
- Speedy Method -					
F. Dial Reading				15.9	
G. Sample Size Factor				1	
H. % Moisture Wet Wt. G x F				15.9	
J. % Moisture Dry Wt. C/E x 100 *	15.9	14.6	10.7	18.9	
Relative Density Determination					
Minimum Specs	65	65	0	0	
Maximum Specs	102	102	115	115	
K. Standard Optimum Moisture	15.4	15.4	15.4	23.5	
L. Relative Moisture % J/K x 100	103	95	69	80	
Curve No.	1	1	1	4	
Inspector: Bev Schroeds	BS	BS	BS	BS	

Project Engineer Kathe Dunbar

See Grading and Base Manual 5-692.253 (M) or 5-692.253 (E)

*J=H/(1-H/100)

Figure 1-692.253M

TP-21850-02 (4/21/02)

Minnesota Department of Transportation

Office of Materials and Road Research

Page No. 6

Relative Moisture Test Grading & Base Construction

S. P. No: 0210-34

Test Identification Data					
Date	7-15-01	7-15	7-16	7-16	
Test No.	33	33A	34	35	
Soil Class or 3138 Class	CL	CL	CL	C	
Station	302+00	301+98	524+00	427+85	
Roadway: Position to Center Line	8' Rt	6' Rt	℄	5' Lt	
Depth Below Grade	2'	2'	6'	4'	
Moisture Determination					
Container No.	A	B	A		
- Burner Method -					
A. Wt. Wet Material + Pan	643	615	576		
B. Wt. Dry Material + Pan	581	556	539		
C. Wt Moisture A-B	62	59	37		
D. Wt Pan	192	152	192		
E. Wt. Dry Soil B-D	389	404	347		
- Speedy Method -					
F. Dial Reading				15.9	
G. Sample Size Factor				1	
H. % Moisture Wet Wt. G x F				15.9	
J. % Moisture Dry Wt. C/E x 100 *	15.9	14.6	10.7	18.9	
Relative Density Determination					
Minimum Specs	65	65	0	0	
Maximum Specs	102	102	115	115	
K. Standard Optimum Moisture	15.4	15.4	15.4	23.5	
L. Relative Moisture % J/K x 100	103	95	69	80	
Curve No.	1	1	1	1	
Inspector: M. Goetz	MG	MG	MG	MG	
Project Engineer Pete Loam					

See Grading and Base Manual 5-692.253 (M) or 5-692.253 (E)

*J=H/(1-H/100)

Figure 1-692.253E

5-692.255 DYNAMIC CONE PENETROMETER (DCP)

A. History and Development

The Dynamic Cone Penetrometer was first introduced to the Minnesota Transportation (Mn/DOT) at the Minnesota Road Research Project (Mn/ROAD). Since 1993 the DCP has been used by Mn/D0T as an acceptance tool for the compaction of pavement edge drain trenches. In 1999, the Penetration Index Method for compaction acceptance of base aggregate Classes 5, 6 and 7 was adopted by Mn/DOT which requires the use of the DCP as the testing device.

B. Description of Device

The Dynamic Cone Penetrometer consists of two 16mm (5/8") diameter shafts coupled near the midpoint. The lower shaft contains an anvil and a pointed tip which is driven into the aggregate by dropping a sliding hammer contained on the upper shaft onto the lower anvil. The underlying aggregate strength (density) is determined by measuring the penetration of the lower shaft into the aggregate after each series of a predetermined number of drops. This value is recorded in millimeters (inches) per blow and is known as the Penetration Index (PI).

C. Equipment

The DCP is comprised of the following elements. (See Fig. 1 5-692.255)

1. Handle: The handle is located at the top of the device. It is used to hold the DCP shafts plumb and to limit the upward movement of the hammer.

2. Hammer: The 8 kg (17.61 lb.) Hammer is manually raised to the bottom of the handle and then dropped (allowed to free fall) to transfer energy through the lower shaft to the cone tip. It is guided by the upper shaft.

3. Upper Shaft: The upper shaft is a 16mm (5/8") diameter steel shaft on which the hammer moves. The length of the upper shaft allows the hammer to drop a distance of 575mm (22.6").

4. Anvil: The anvil serves as the lower stopping mechanism for the hammer. It also serves as a connector between the upper and lower shaft. This allows for disassembly which reduces the size of the instrument for transport.

5. Lower Shaft: The lower shaft is a 16mm (5/8") diameter steel shaft, 900-1200mm (35-47") long, marked in 5mm (0.2") increments for recording the penetration after each hammer drop.

6. Cone: The cone measures 20mm (0.787") in diameter. The cone tip should have a 60 degree angle. (See Fig. 2 5-692.255)

D. Operation Points of Caution

1. Always use caution to avoid pinching fingers between the hammer and the anvil. during testing, use the handle to hold shafts plumb. **Do not hold the DCP near the anvil area.**

2. It is important to lift the hammer slowly and drop it cleanly, allowing at least two seconds to elapse between drops. Lifting and dropping too rapidly may affect results because the hammer's full energy may not be allowed to transfer to the lower shaft. This will cause incorrect test results.

E. Test Procedure - Base Aggregate(2211.3C3)

1. Locate a level and undisturbed area (test site) that is representative of the material to be tested.

2. Place the DCP device on the base aggregate test site. To properly seat the DCP (coned tip), two hammer blows are required. Therefore, carefully raise the sliding weighted hammer until it meets the handle, then release the hammer under its own weight. Repeat this process one more time for a total of two complete blows. If the seating processes cause initial penetration exceeding 40mm (1.6"), move the test site at least 300mm (12") from the previous test location and reseat the cone. If the second test site still does not meet the seating criteria, DCP testing for density can not proceed. The area being tested must be recompacted.

3. Record the penetration measurement after seating using the graduated rule on the DCP. The measurement is taken to the nearest 2.5mm (0. 1 "). (Use form TP-2170). (See Fig. 3 5-692.255)

4. Carefully raise the hammer until it meets the handle, then release the hammer under its own weight. Repeat this process two more times for a total of three times.

5. Record the final penetration measurement using the graduated rule on the DCP. The measurement is taken to the nearest 2.5mm (0.1”).

6. Subtract the measurement in step 3 from the measurement in step 5 and then divide the difference of the measurements by the number of blows (3) required for testing. If necessary, follow the formula on the test form to convert from inches to mm. Round-off all test results to the nearest mm or one-tenth of an inch. (See Grading and Base Manual 5-692.805).

F Test Procedure - Edge Drain Trench Filter Aggregate(2502)

1. After the compaction of the first 15m (50') of filter aggregate within the edge drain trench has been completed, determine the location of three test sites that are 3m (10") apart within that first 15m (50').

2. Calculate the number of hammer drops (blows) necessary to 'properly test the trench filter aggregate but not damage the edge drain pipe by subtracting 150mm (6") from the depth of the trench to be tested and dividing that total by **75** for metric measurements or **3** for English measurements. If necessary, round this number <u>down</u> to the next whole number. (See Fig. 4 5-692.255)

   Example: If the trench depth equals 650mm (26").
   then 650mm (26") minus 150mm (6") equals 500mm (20").
   then 500mm (20") divided by 75(for Metric) or 3 (for English) equals 6.7 or 6.

3. Place the DCP on test site #1 and seat the coned tip of the device by slightly taping the lower anvil with the hammer until the coned tip is just out of sight.

4. After seating, record the penetration measurement using the graduated rule on the DCP. The measurement is taken to the nearest 2.5mm (0. 1"). (Use form TP-2170) (See Fig. 5 5-692.255)

5. Carefully raise the hammer until it meets the handle, then release the hammer under its own weight. Repeat this process until the total number of hammer drops equals the required number of blows as calculated in step 2. Also, beware and avoid the chance of penetrating the edge drain pipe at the bottom of the trench when the compaction of the trench is less than passing.

6. Record the final penetration measurement from the graduated rule on the DCP. The measurement is taken to the nearest 2.5mm (0.1”)

7. Subtract the measurement in step 4 from the measurement in, step 6 and then divide the difference of the measurements by the number of blows required for testing. The result is the penetration index. If necessary, follow the formula on the test form to convert from inches to mm.

8. Use the same procedures as outlined above for testing sites #2 and #3.

9. Add the three penetration index results from test site #1, #2 and #3 and divide that total by 3 in order to calculate the average of all three tests. Round-off the average of the tests to the nearest mm (0.1"). (See Grading and Base Manual 5-692.805)

G. Maintenance and Handling

Because the Dynamic Cone Penetrometer is driven into the ground, sometimes into very hard soil layers, regular maintenance and care are required. To ensure that the DCP operates properly, the following guidelines must be followed.

1. Monitor the condition of the connection bolt. Extra bolts should be kept in the DCP carrying case because they frequently become stripped or broken and may need to be replaced during testing.

2. Keep the upper shaft clean. Lubricate very lightly with oil if binding develops. Frequently wipe both shafts clean with a soft cloth during use.

3. Monitor the DCP for excessive wear on any of the components and make repairs as needed. Because the DCP is a standardized testing device, its overall weight and dimensions must not change from specifications.

4. The cone tip should be replaced when the diameter of its widest section is reduced by more the 10 percent (2mm [0.08 inch]) or the cone's surface is gouged by rocks. Inspect the cone tip before and after each test. Nevertheless, the cone tip should be replaced at least once a year.

5. Never extract the DCP from the test hole by forcefully striking the hammer against the handle. Striking the handle causes accelerated wear and may lead to broken welds and connections. At least once a year, all welds on the DCP should be critically inspected for hairline or larger cracks.

6. Do not lay the device on the ground when not in use. The DCP should be kept in its carrying case to avoid bending the shafts. Straightness of the shafts is extremely important. The hammer can not free fall if the shafts are bent. The straightness of the shafts should be critically measured and reviewed each year prior to the start of construction season.

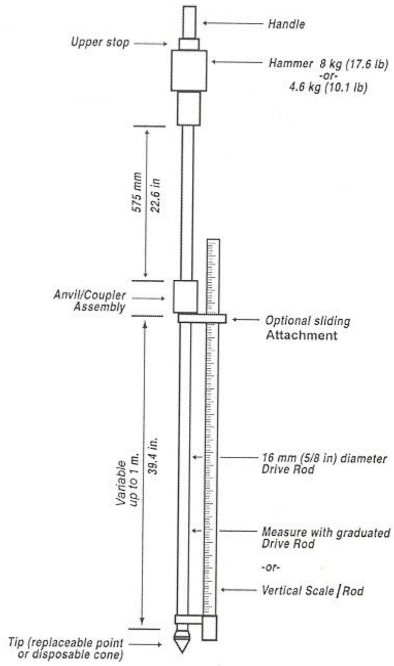


Figure 1 - Schematic of DCP Device

Fig. 1 5-692.255

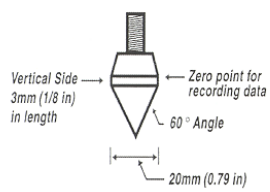


Figure 2 - Replaceable Point Tip

Fig. 2 5-692.255

Minnesota Department of Transportation

Office of Materials and Road Research

TP-2170-02 (7/2000)

Density Test for Base Aggregate and Edge Drain Trench Filter Aggregate

(Penetration Index Method by DCP*)

SP 0215-18 TH 10 Tester D.C. Pea

LOC Anoka DIST. MW

Test No.	Aggregate Class or Filter Aggregate	Station	Lift Thickness or Trench Depth	(A) 2nd Reading	(B) 1st Reading	(C) Difference	(D) Blows	(E) Penetration Index (PI)	(**) Edge Drain (PI) Average	Pass or Fail	Date
1	5	25+00	6"	5.9"	4.9"	1.0"	3	0.3"/8mm		P	5-18-02
2	5	26+25	6"	6.0"	4.8"	1.2"	3	0.4"/10mm			
3	7B	18+10	3"	4.8"	3.7	1.1"	3	0.4"/10mm		P	5-20-02
4	7B	21+05	3"	4.6"	3.7	0.9"	3	0.3"/8mm			

See Grading and Base Manual

(**) Used for Edge Drain Tests Only
*Dynamic Cone Penetrometer

For Base Aggregate
C = A – B
E = C ÷ D
(Conversion from inches to mm = E x 25)
Penetration Index (E) = 10 mm (0.4 in.) or less = Passing

For Filter Aggregate
C = A – B
E = C ÷ D
(Conversion from inches to mm = E x 25)
Penetration Index (E) = 75 mm (3 in.) or less = Passing

cc: Project File

Fig. 3 5-692.255

Edge Drain Trench
w/filter aggregate

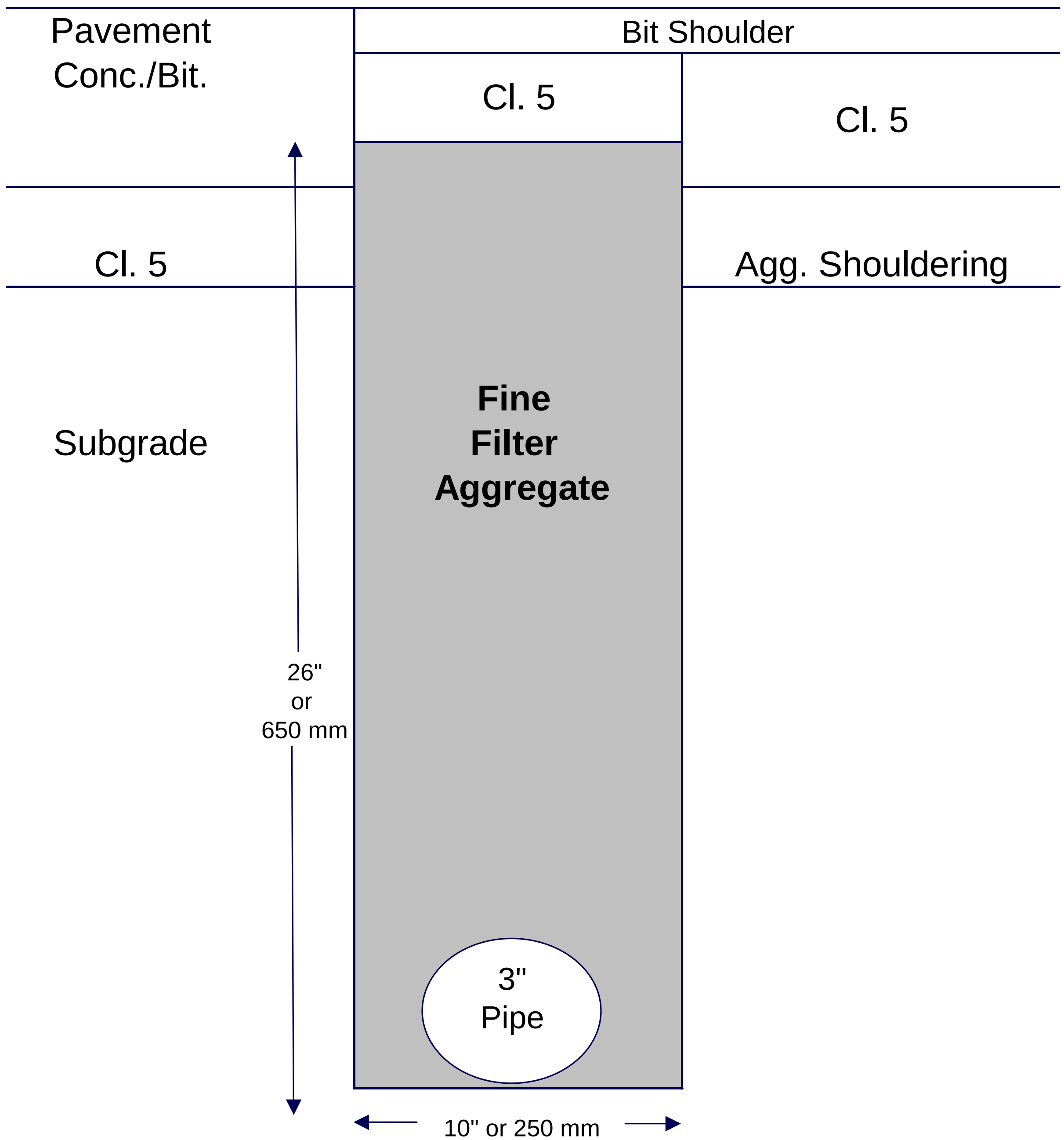


Fig. 4 5-692.255

TP-2170-02 (7/2000)

Minnesota Department of Transportation

Office of Materials and Road Research

Density Test for Base Aggregate and Edge Drain Trench Filter Aggregate

(Penetration Index Method by DCP*)

SP 6208-144 TH 10 Tester Max Density

LOC St. Paul DIST. ME

Test No.	Aggregate Class or Filter Aggregate	Station	Lift Thickness or Trench Depth	(A) 2nd Reading	(B) 1st Reading	(C) Difference	(D) Blows	(E) Penetration Index (PI)	(**) Edge Drain (PI) Average	Pass or Fail	Date
12	FA	28+10	20"/500mm	19.2"	1.5"	17.7"	6	3.0			
13	FA	28+20	✓	18.2"	1.3"	16.9"	6	2.8			
14	FA	28+30	✓	18.8"	1.5"	17.3"	6	2.9			
								8.7/3 =	2.9"/72mm	P	5-26-02

See Grading and Base Manual

(**) Used for Edge Drain Tests Only
*Dynamic Cone Penetrometer

For Base Aggregate

C = A – B
E = C ÷ D

(Conversion from inches to mm = E x 25)
Penetration Index (E) = 10 mm (0.4 in.) or less = Passing

For Filter Aggregate

C = A – B
E = C ÷ D

(Conversion from inches to mm = E x 25)
Penetration Index (E) = 75 mm (3 in.) or less = Passing

cc: Project File

Fig. 5 5-692.255

5-692.260 PULVERIZATION DETERMINATION FOR BINDER SOILS

A. Scope

This method of test covers a procedure for the field determination of the degree of pulverization of binder soils.

B. Apparatus

1. 27.2 kg (30 lb.) capacity dairy scale with decimal graduations in tenths of a kilogram(lb.) (Interpolate reading to the nearest 0.05 kg) (for metric only.)
2. Two 12 (quart) liter pails
3. 19 mm (3/4”) sieve, 4.75 mm No. 4) sieve

C. Procedure

1. For rate of testing see Table A 5-692.100.
2. Obtain a representative sample weighing approximately 15 kg (30 lb.).
3. Use the moist weight for all computations.
4. Record the moist weight of the sample.
5. Pass the sample through the required sieve sizes in such a manner that disintegration of the soil clods will not occur. The fraction retained on each sieve shall be weighed on the dairy scale and the weight recorded.
6. The percent of material passing each sieve size is computed as follows:

$$\frac{\text{(Moist wt. of material passing sieve size)}}{\text{Moist weight of total sample)}} \times 100$$

D. Retained in field diary.

5-692.270 TEST ROLLING

A. Scope

Test rolling of subgrades with a heavy roller is a procedure performed to evaluate the adequacy of the roadbed construction relative to uniformity and consistency of the subgrade support in terms of strength, stiffness, density and moisture content. The test roller will detect weak /unstable subgrade areas due to inadequate compaction (both in terms of moisture content and density), and/or unstable soils to a depth of five feet. The detected failed areas will require corrective measures. These measures may include removing the unstable/unsuitable soils, reducing the moisture content by aeration and the recompaction of the soil, etc.

B. Equipment

1. The test roller shall comply with the provisions of Specification 2111. The Inspector should check the equipment for compliance.
2. The test roller shall be weighed. If certified weights are furnished, these may be accepted. Special care could be taken to measure tire pressure correctly.
3. The test roller shall be towed. Self-propelled test rollers are unacceptable.

C. Procedure
The procedure is provided in Specification 2111.

D. Record
The roller, weights, tire pressure, and record of failing areas should be recorded in the Inspector's diary.

E. Relation of Test to Construction
Test rolling failures are generally related to excessive moisture, lack of density, or unsuitable soil. Weak areas disclosed by the test roller should be investigated and the cause determined. The failing areas should then be corrected and re-tested as provided for in Specification 2111.

E. Test rolling in accordance with Mn/DOT 2111 is <u>not</u>, generally, recommended for the following situations.

1. Subcut areas that are less than 750 mm (30 inches) in depth. (Test rolling areas with shallow excavations probably will not pass the 2111 requirements.)
2. Roadbed construction within municipalities having shallow underground utilities.
3. Roadway segments with numerous, closely spaced, shallow, underground structure (culvert, storm sewers, other utilities, etc.) In all situations where test rolling is utilized, shallow structures must be protected against damage from the test roller. Structures should have at least 750 mm (30 inches) of soil cover prior to testing the subgrade. This depth may require the temporary increase in soil cover over the structure (construction of a blister).
4. Roadway segments with relatively closely spaced bridge overpasses.
5. Areas where geosynthetics are placed within the upper 1.7 meters (five feet) of the embankment.

5-692.300
REPORTS

Minnesota Department of Transportation

Office of Materials and Road Research

TP-02115-03 (7-2000)

FINAL

Monthly Grading and Base Report

Report No.: 16

S. P. No.: 0280-172

T.H. No.: 35

Contractor: Full Cooperation, Inc.

Inspector: Mareen Core

Submit on same date as monthly estimate.

Date: April 30, 2001

GRADING MATERIALS

Excavation Class	Cubic Meters (yards) To Date	Minimum Test Rate*	Moisture Tests Required	Moisture Tests Made	Moisture Tests Uncorrected	Density Tests Required	Density Tests Made	Density Tests Uncorrected
Common	1,258,700	2600 / 4000	485	571	0	315	340	0
Subgrade	* 256,940	2600 / 4000	99	113	2 **	65	74	0
Granular Borrow	83,000	0 / 0	0	(Swamp Backfill – No Tests)				
Common Borrow	151,667	0 / 0	0	(Quality Compaction – Shld. Widening)				
Unclassified								
	Plus * 35,000	0 / 0	Unsuitable – Wasted In Borrow Pit					

**See Grading & Base Manual 5-692.301*

BASE MATERIALS

Aggregate Class	Cubic Meters (yards) or Tons to Date	Minimum Test Rate**	Gradation Tests Required	Gradation Tests Made	Gradation Tests Uncorrected	Density Tests Required	Density Tests Made	Density Tests Uncorrected
Class 1	1920 ton	1000 / 0	2	2	0	Qual. Comp.		
Class 2	390 ton	0 / 0	Form 2415 – Sm. Quan. – Qual. Comp.					
Class 3								
Class 4								
Class 5	55870 ton	10000 / 1800	6 Lots	8 Lots	*** 1 Lot	32	34	0
Class 6								
Class 7 B	18,480 ton	10000 / 2/1800	2 Lots	2 Lots	0	22 DCP	22 DCP	0
Gran. Borr.	(LV) 83,000 cy³	— / 0	7	7	0	– See above		–

***See Grading & Base Manual 5-692.301*

Grading 100 % complete; Base 100 % complete

Shouldering 100 %

** *** ☒ Remarks on reverse side.

cc: Grading & Base Engineer (Mn/DOT Projects Only)
Project File

Project Engineer: D. Grebeb

Figure 1 5-692.300

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5-692.301 MONTHLY GRADING & BASE REPORT

See Fig. 1 5-692.300 or Fig. 2 5-692.300.

A. The Monthly Grading and Base Report Form 02115 is used by the Project Engineer to report information needed by the Grading and Base Construction Engineer. The form must be completed for all federally funded state, county and municipal projects containing grading and base items, even when no physical sampling or testing is required.

Two weeks after the actual starting time of construction, the first report should be completed and the white copy sent promptly to the Grading and Base Office. The first report is expected whether or not the construction being performed includes any grading and base items. The second and all other reports, through the final should be submitted on a monthly basis on the same day as the monthly estimate. An exception can be made to the submittal date for other than the first report so long as the monthly rate is adhered to.

B. Use the following guidelines when preparing the report.

1. Use the lowest S.P. Number.
2. Fill out form 02115 completely. In the first column insert the item name. Do not use the specification pay item number. The most commonly used item designations have been printed on the form. A blank space has been provided for special items such as filter blanket material, subdrain backfill, etc.
3. Record the cumulative quantities for each class of material placed up to the date of the monthly estimate.
4. Insert the minimum testing rate for the class of material. This information is contained on form SD-15, Table A 5-692.100. For grading materials, place the rate for moisture tests on the left and the rate for density tests on the right. For base materials, place the gradation test rate on the left and the density rate on the right.
5. Under each of the test designations there are three columns headed "Required," "Made" and "Uncorrected."
   a. "Required." In this column, enter the number of tests required for the quantity of material listed. For example, the rate for gradation tests for class 5 base aggregate is one lot (4 tests averaged) per 10,000 ton. If the "Required" column indicates that 55,870 ton of class 5 aggregate has been placed, determine the number of tests required by dividing the quantity by the rate. In this case, it would be:

$$\frac{55{,}870}{10{,}000} = 6 \text{ lots required}$$

For projects with pay items for aggregate in cubic meters or cubic yards, the conversions from metric tons and English tons are as follows:

1 metric ton = 0.6 cubic meter (1 ton = 0.7 cubic yard) (LV)
1 metric ton = 0.46 cubic meter (1 ton = 0.55 cubic yard) (LV)

Please keep in mind, however, that many times it may be necessary to run more than the minimum number of tests to control the acceptance of materials or the contractor’s procedures.

Also, when determining the rate of sampling for moisture and density tests on embankment soils or base or shouldering aggregates, great attention should be given to detail. The correct pay quantity and units of measure of the materials to be tested should be reviewed. The fact that a project may be in metric or English and compacted volume (CV) or loose volume (LV) can lead to testing rate calculation errors.

When completing the form each month, do not overstate the number of density, moisture and gradation tests required. Include only the estimated number required up to the date of the report. In other words, at worst, the number of tests actually made should never be more than a few less than the number required. This could happen because of a tester's heavy workload, the weather, or other reasons. Usually, the number of tests made will exceed the minimum number required. It is not necessary to keep a separate count of moisture or density tests run on embankments (or subcut backfills) built from different classes of excavation material. When estimating required tests, do not include unsuitable material or material placed in areas not required to be compacted (some swamps, or shoulder widening embankments placed under quality compaction).

   b. In the column headed "Made," enter the number of tests made.

c. In the column headed "Uncorrected," enter only the number of failing tests that have not been corrected.

6. Remarks: Use the "Remarks" area on the back of the form to communicate the progress of the grading and/or base portion of the contract. The contractor has options that may affect some of the data needed to finalize the job. For example, he may decide to use all Class 5 aggregate for the base and shoulder, or use class 7B in lieu of class 6 base aggregate. When all grading and base items (that require testing) have been placed and tested the project is considered completed—at least as far as the Grading and Base Unit is concerned. At this time a "Final" Monthly Grading and Base Report should be issued. The "Final" report shall be a summary of quantities and test data for all the grading and base work performed. The pay quantities reported need not be the final quantities reported on the Final Estimate—estimated final quantities are good enough. Include items added by Supplemental Agreement. Items that may have been eliminated should be mentioned and uncorrected failing tests explained.

C. For all projects that utilize the grading and base portion of the CONLAB computer program, a partial computer generated Monthly Grading and Base Report can be used. (See Fig. 2 5-692.300).

1. The column “Quantity To Date” must be completed with the most up-to-date estimate of the various quantities.
2. The “Report Number” in ascending sequential order must be placed on the report.
3. The “% Completed” line must be filled in for the total <u>Grading</u>, <u>Base</u> and <u>Shouldering</u> used.
4. The lines for the project engineer and chief inspector’s name along with their telephone or pager numbers must be completed.
5. The comments or remarks area is also available for “tidbits” of information of interest to the Grading and Base Unit.
6. The partial computer generated Monthly G&B Report is due in the Grading and Base Unit during the first week of every month of construction.

5-692.312 TEST RESULTS NOT TABULATED BY CONLAB

A. The results of field moisture, field density, and field gradation tests required for materials used for grading and base construction on non CONLAB state projects, county projects, municipal projects or maintenance projects shall be recapped on the Form 21760-03b, Relative Moisture and Relative Density Report (side 1) and Form 21760-03a, Field Gradation Test Report (side 2). See Figures 1M, 2M and 3M 5-692.312 for a metric example and Figures 1E, 2E and 3E 5-692-312 for an English example.

B. If the work is conducted under Specified Density procedures, moisture and density tests are required and side 1 of Form 21760-03b is used for reporting the test results (Fig. 1M & 2M or 1E & 2E 5-692.312). The depth of test for grading construction is measured in meters (feet) from the grading grade and depth of test for base and shoulder construction is measured in millimeters (inches) from the top of the finished base or shoulder before paving.

C. Side 2 of Form 21760-03a is used for gradation test results except for aggregate tested under the Random Sampling Gradation Acceptance Method. All other material that has a gradation requirement must be tested and their results recorded (Fig. 3M or 3E 5-692-312). Please note tht because of the many possible modified specifications, test results reported without including the requirements are considered incomplete and will have to be returned to the Engineer for completion.

TP-21760-03b (5/2002)

Minnesota Department of Transportation

Office of Materials and Road Research

Moisture, Density or Penetration Summary

S.P. No. 1980-148
Report No. 2
Date July 10, 2001

Note: The relative moisture test must be performed at the time of compaction; it is a separate test: not part of the relative density test

Test #	Station	Depth of Test m or mm (ft) or (in)	Soil Class or 3138 Class	Moisture-Density Tests: Curve No.	Opt. Moist. %	Max. Dens. kg/m³ (lb/ft³)	Roadbed Tests: Moisture, ~~Density~~ or DCP %, kg/m3 (lb/ft³) or mm (in.)	Required* %	Field Results* %	Date and Remarks
51	165+500	1.5	SL	3	17.9		18.5	0-115	103	7-2
52	185+010	0.9	CL	2	15.0		17.0	65-102	113	✓ Fails
53	167+874	1.0	SL	3	17.9		18.0	0-115	101	✓
52A	185+010	0.9	CL	2	15.0		15.0	65-102	100	7-3
Base —										
1	350+100	75mm	Cl.4	2	11.7		8.8	65+	75	7-1
2	353+600	✓	✓	✓	✓		10.0	✓	85	✓
3	353+580	✓	✓	✓	✓		12.0	✓	103	✓
4	165+100	150 mm	Cl.3	3	11.7		11.6	✓	99	7-3
Base — DCP										
10	353+600	150 mm	Cl.5				6.1	5-8%		7-6
11	353+640	✓	✓				✓	✓		✓
12	353+685	✓	✓				6.8	✓		7-8
13	354+006	✓	✓				✓	✓		✓

*Moisture, Density or DCP

See Grading and Base Manual Fig 2 5-692.312

Tester Pete Lohm

cc:Project File

Figure 1M 5-692.312

TP-21760-03b (5/2002)

Minnesota Department of Transportation

Office of Materials and Road Research

Moisture, Density or Penetration Summary

S.P. No. 1980-148
Report No. 2
Date July 10, 2001

Note: The relative moisture test must be performed at the time of compaction; it is a separate test: not part of the relative density test

Test #	Station	Depth of Test m or mm (ft) or (in)	Soil Class or 3138 Class	Moisture-Density Tests: Curve No.	Opt. Moist. %	Max. Dens. kg/m³ (lb/ft³)	Roadbed Tests: ~~Moisture~~, Density or DCP %, kg/m3 (lb/ft³) or mm (in.)	Required* %	Field Results* %	Date and Remarks
32	164+400	1.0	SL	3		1668	1604	95+	96	7-8
33	180+100	0.3	✓	✓		✓	1670	100+	100	7-9
34	166+500	0	S	4		1845	1930	✓	105	✓
35	167+510	0.7	SL	3		1668	1748	✓	105	7-10
	Base	—								
1	190+110	75mm	Cl.4	12		2053	2012	100+	98	7-2 Fails
2	198+775	✓	✓	✓		✓	2097	✓	102	7-2
3	189+700	✓	✓	✓		✓	2135	✓	104	✓
1A	190+110	✓	✓	✓		✓	2061	✓	100	7-6
	Base	— DCP								
10	15+800	150mm	Cl.6					PI 10−	8.3	7-7
11	17+673	✓	✓					✓	8.7	✓
12	19+810	✓	✓					✓	10.0	7-8
13	18+430	✓	✓					✓	9.3	✓

*Moisture, Density or DCP

See Grading and Base Manual Fig 2 5-692.312

Tester Pete Lohm

cc:Project File

Figure 2M 5-692.312

TP-21760-03a (5/2002)

Minnesota Department of Transportation

Office of Materials and Road Research

S.P. No. 1980-148

Report No. 2

Date July 10, 2001

Field Gradation Test Report

Note: Submit specification requirements with each group of tests.

Test #	Station	3138 Class or 3149	Aggregate Gradation - % Passing Square Opening Sieves									% Crush	75 µm/25 mm (#200/ 1 in)	Date
			75 mm (3 in.)	50 mm (2 in.)	25 mm (1 in.)	19 mm (3/4 in.)	9.5 mm (3/8 in.)	4.75 mm (#4)	2 mm (#10)	425 µm (#40)	75 µm (#200)			
3	250+131	GB			90						10.5		11.7	6-30
4	250+911	✓			89						15.6		17.5	7-5
5	252+203	✓			95						7.9		8.3	7-8
								Required				—	0-20	
2	248+609	SGB			100						4.4		4.4	6-29
								Required				—	0-12	
1	248+776	Agg. Bed			100	95	69	59	44	18	7.1	18.3		6-26
		Required	—		100	90-100	50-90	35-80	20-65	10-35	3-10	10.0+		
		Class 1 — Random Sampled												
					(Results on another form)									
		Class 5 — Random Sampled												
					(Results on another form)									

See Grading and Base Manual Fig 2 5-692.312

Tester Pete Lohm

cc:Project File

Figure 3M 5-692.312

TP-21760-03b (5/2002)

Minnesota Department of Transportation

Office of Materials and Road Research

Moisture, Density or Penetration Summary

S.P. No. 2762-09
Report No. 7
Date 11-2-01

Note: The relative moisture test must be performed at the time of compaction; it is a separate test: not part of the relative density test

Test #	Station	Depth of Test m or mm (ft) or (in)	Soil Class or 3138 Class	Moisture-Density Tests Curve No.	Opt. Moist. %	Max. Dens. kg/m^3 (lb/ft^3)	Roadbed Tests Moisture, ~~Density~~ or DCP %, kg/m3 (lb/ft^3) or mm (in.)	Required* %	Field Results* %	Date and Remarks
109	WB5 1399+00	1'	SL	9	12.0		8.0	65-102	67	10-1
110	WB5 1191+60	12'	GRAN.	2	9.4		4.4	0-115	47	✓
111	1195+00	15'	SL	9	12.0		9.8	✓	82	10-2
112	1191+36	12'	SL	7	12.7		9.6	✓	76	✓
	Base	—								
16	18+10	6"	3	14	9.1		6.9	65+	76	10-25
17	19+50	✓	3	✓	✓		7.0	✓	77	10-26
	Base	— DCP								
22	18+15	3"	7B					5-8%	7.7	10-28
23	18+80	✓	✓					✓	✓	✓
24	22+10	✓	✓					✓	7.8	✓
25	23+94	✓	✓					✓	✓	✓

*Moisture, Density or DCP

See Grading and Base Manual Fig 2 5-692.312

Tester Kevin Roaming

cc:Project File

Figure 1E 5-692.312

TP-21760-03b (5/2002)

Minnesota Department of Transportation

Office of Materials and Road Research

S.P. No. 2762-09
Report No. 7
Date 10-28-01

Moisture, Density or Penetration Summary

Note: The relative moisture test must be performed at the time of compaction; it is a separate test: not part of the relative density test

Test #	Station	Depth of Test m or mm (ft) or (in)	Soil Class or 3138 Class	Moisture-Density Tests Curve No.	Opt. Moist. %	Max. Dens. kg/m3 (lb/ft3)	Roadbed Tests ~~Moisture~~, Density or DCP %, kg/m3 (lb/ft3) or mm (in.)	Required* %	Field Results* %	Date and Remarks
79	WB 212 1399+00	1'	SL	7		119.4	114.5	100	96	10-1 JH Fails
79A	✓	1'	✓	✓		✓	120.0	✓	100	✓ JH
80	WB 5 1191+80	12'	✓	8		127.0	126.1	95	99	✓ JH
81	1195+00	12'	✓	3		120.9	112.9	✓	95	10-3 JH
82	1191+36	9'	✓	8		127.0	129.4	✓	102	✓ JH
	Base —									
14	18+10	6"	Cl.3	14		115.3	117.1	100	102	10-26 HM
15	19+30	✓	Cl.3	✓		✓	115.9	✓	101	✓ HM
	Base – DCP									
38	18+50	6"	Cl.5					PI 0.4"–	0.3"	10-26 HM
39	19+10	✓	✓					✓	✓	✓ HM
40	22+48	✓	✓					✓	✓	✓ HM
41	25+22	✓	✓					✓	✓	✓ HM
42	25+90	✓	✓					✓	0.4	10-27 HM
43	28+00	✓	✓					✓	0.3	✓ HM

*Moisture, Density or DCP

See Grading and Base Manual Fig 2 5-692.312

Tester John Heakle + Henry Mailman

cc:Project File

Figure 2E 5-692.312

TP-21760-03a (5/2002)

Minnesota Department of Transportation

Office of Materials and Road Research

S.P. No. 2762-09

Report No. 7

Date 11-2-01

Field Gradation Test Report

Note: Submit specification requirements with each group of tests.

Test #	Station	3138 Class or 3149	Aggregate Gradation - % Passing Square Opening Sieves: 75 mm (3 in.)	50 mm (2 in.)	25 mm (1 in.)	19 mm (3/4 in.)	9.5 mm (3/8 in.)	4.75 mm (#4)	2 mm (#10)	425 µm (#40)	75 µm (#200)	% Crush	75 µm/25 mm (#200/ 1 in)	Date
16	Wall 9	SGB			100						5.5		5.5	10-6
17	EB 5 1191+50	✓			100						4.6		4.6	10-15
								Required				—	0-12	
15	W. Abut Br. 27194	SGB (Mod)			96						5.3		5.5	10-4
								Required				—	0-10	
18	WB 212 1399+00	Stab. Agg.			100	97	86	73	61	29	8.9	22.1		10-19
	Required	—			100	90-100	50-95	35-85	20-70	10-45	7-15	10.0+		
19	Wall 8	Gran. Back	100		92						14.4		15.7	10-22
	Required	—	100										0-20	
		Class 5		— Random Sampled										
						(Results on another form)								

See Grading and Base Manual Fig 2 5-692.312

Tester Clayton Lumpps

cc:Project File

Figure 3E 5-692.312

5-692.315 MATERIALS CERTIFICATION

(See Fig. 1, 5-692.315)

A. The Materials Certification Exception Summary TP-02171 is used to certify that all grading and base materials incorporated into the project have been inspected, tested and accepted. This document assures conformance with the approved plans, specifications, special provisions and the Schedule of Materials Control. All nonconforming items (exceptions) must have a documented resolution. Missing tests and reports, uncorrected failing tests, lab/field tolerance failures and tests performed by non-certified personnel are considered exceptions.

   ** **The most current version of this form is available at http://www.mrr.dot.state.mn.us/materials/materials.asp.**

   This form is required for Final Certification and must be completed before the Final Estimate is completed and printed. The Project Engineer is required to sign and place his/her Minnesota Professional Engineer number on the completed form.

   The completed form is forwarded to the district/division Materials Engineer for information regarding Independent Assurance reviews and associated laboratory tests. The District Materials Engineer must sign and return the completed form to the Project Engineer.

   This signed form becomes part of the finals package and the Project Engineer distributes the copies.

   The project personnel's responsibility for materials certification is now completed; unless unreported exceptions are discovered in audits by the Materials Engineer, Central Inspection Engineer or the Grading and Base Engineer.

B. Use the following guidelines, when preparing the Materials Certification form.
   1. Place an "X" by Grading and Base.
   2. Use the lowest SP number, Contract No. and Project Description.
   3. Fill in the Trunk Highway or CSAH number.
   4. Enter the Mn/DOT District or the County's or City's name.
   5. Enter the location of the project.
   6. Enter the Contractor and Project Engineer/Supervisor's name.
   7. Review all Grading and Base items for:
      a. Quantities used
      b. Change Orders and Supplemental Agreements
      c. The number of tests required and performed
      d. Resolution of failing test results
      e. Resolution of out-of-tolerance field/laboratory companion tests
   8. Enter all exceptions. See 5-692.316 and the example on 5-692.317 or if none, enter "NONE".
   9. Enter the Federal No.
   10. District/Metro Materials Engineer must sign form.
   11. Resident or Project Engineer must sign form.

C. Certification Audit
   Approximately 15-30 project certifications may be audited every year. The projects are picked at random, although there is an effort to get at least one project audited from each resident office in every district.

   If a project is chosen to be audited, the resident engineer will receive a request for all project materials inspection and testing records to be sent to the Audit Manager at the Maplewood Laboratory. The records will be due in Maplewood within two weeks of the request. The project files will be reviewed by the appropriate Specialist Offices (Grading and Base, Bituminous or Concrete). After the audit has been completed, the resident engineer is encouraged to respond to the audit at that time with any questions or give further statements to correct any discrepancies or misunderstandings about the final audit results.

MATERIALS CERTIFICATION EXCEPTIONS SUMMARY

S.P. No. 4013-41	Contract No. 10385	Project Description Widening, Bit & Conc. Curbs	Const. Year 2001
T.H. 169	District 7	Contractor Hi Tech Contracting	Project Location Le Sueur
Project Engineer/Supervisor Phil Section		Federal No. BSH 1410	Page 1 of 1

Materials and products used on project: (check all boxes that apply)

- [x] Grading and Base
- [x] Bituminous
- [x] Concrete
- [ ] Aggregate
- [ ] Materials/Chemicals

Specialty	Exception Description	Resolution	Document Reference	Name/ Initials
G&B	Two class 5 field gradations failed on #200	See C.O. #4		DB
G&B	13 field density tests req. - 12 tests completed	Substancially Complying		DB
G&B	Two moisture tests left unconnected in upper 3 feet	All density tests passed.		CE
G&B	One class 5 lot (8,120 ton) failed on the 3/8" & #40 sieves	See C.O. #6		DB
Bit	No Exceptions			SB
Conc.	No Exceptions			MR

Form TP-02171-04

Sandy Fields — District/Metro Materials Engineer — Date 9-2-01

Phil Section — Project Engineer — Date 9-4-01

ATTACH SUMMARY REPORTS OF SUPPLEMENTAL/AGREEMENTS, CHANGE ORDERS and BACKSHEET ITEM EXCEPTIONS.

- [ ] No Independent Assurance Required
- [ ] Independent Assurance Not Completed
- [x] Independent Assurance Completed Without Exceptions
- [ ] Independent Assurance Completed With Exceptions

Information regarding Independent Assurance is available in the District I.A. or Project Engineer Files

Original: Retain in Project file
Copy: State Materials Testing Engineer – MS 645
Copy: Financial Operations Section – MS 215
Copy: District Materials Engineer
Copy: Office of Construction and Contract Administration – MS 650

Figure 1 5-692.315

CERTIFICATION AUDIT

Page 1 of 1

To: Audit Manager
Subj: Materials Certification Audit

The Grading & Base certification audit was completed on 3-15-01 for SP 1908-52 by Vera Stern of the Grading & Base Office

The followings questions, concerns and/or comments are listed below:

1. No Class 5 crushing test results were on file.
2. The extraction test for the Class 7B base aggregate used could not be found.
3. The project personnel certification memo could not be found.
4. The organization of this project file was excellent and very easy to audit.

Vera Stern
Auditor

cc:
Specialist Office
(G&B or Bit. or Conc.)

Figure 2 5-692.315

5-692.316 REQUIREMENTS FOR CERTIFICATION

A. Possible tests/samples required for any project as per current Schedule of Materials Control. (Field and/or Laboratory)
   1. Proctor tests
   2. Moisture tests
   3. Density tests
   4. DCP tests
   5. Gradation tests
   6. Crushing tests
   7. Quality tests
   8. Bituminous extraction for aggregate with salvaged bituminous

B. Laboratory and field tests
   1. Copies of all laboratory test results/reports on file. (Reports must contain field companion results.)
   2. Copies of all field test results on file.
      (All acceptance samples must be taken from the roadway except for Classes 1, 2 & 7 shoulder surfacing aggregates tested and accepted under the Specification 3138.3.)
   3. A summary and average of all stockpile acceptance tests

C. Independent Assurance requirements of file
   1. Certification of project personnel
   2. Required I.A. inspections - (gradations and/or densities)
   3. All required I.A. out-of-tolerance testing form 24355's are completed

D. Other required forms on file
   1. Current certification form
   2. All Monthly Grading and Base Reports (form 02115) or equivalent Con-Lab Reports.
   3. Summary of gradation results and/or moisture and density tests on form TP21760
   4. Aggregate Certification form(s) TP24346
   5. Glass certification letters

5-692.400
FIELD INSPECTION OF MATERIALS

5-692.401 CULVERT INSPECTION AND INSTALLATION

The final inspection and acceptance of culvert pipe is made on the projects. A preliminary inspection is also made at the producing plant by a representative of the Office of Materials. The culvert should be rejected if the field inspection reveals it to be defective.

A. Concrete Pipe

The plant inspection of concrete pipe includes the sampling and testing of the materials used in the manufacture of the pipe and a 3 edge bearing test. In lieu of the bearing test, cores are sometimes drilled from the pipe and tested in the laboratory.

The finished product is also inspected at the plant. Because the pipe are stockpiled at the plant, it is not always possible to make a close inspection of each length of pipe. For this reason and because of the possibility of damage in shipping or handling, the pipe should be visually inspected on the project before it is installed. Visual inspection should include the following items:

1. Fractures and cracks that extended all the way through the wall of the pipe: Fractures in the tongue or groove ends are not cause for rejection, provided that they can be satisfactorily repaired.
2. Honeycombing: Excessive honeycomb can reduce the strength of the pipe.
3. Steel obviously misplaced: This would include exposed steel and wire projecting from the end of the barrel. (The exposure of the ends of stirrups or spacers that have been used to position the reinforcing steel during placement of the concrete shall not be considered cause for rejection.)
4. It is not necessary to measure every pipe. Each lot delivered should be spot checked for compliance.
5. Check each pipe for the class, date and trademark.

B. Metal Pipes

The plant inspection of metal pipes includes the periodic sampling and testing of the materials used in the manufacture of the pipes.

Pipes are visually inspected at the plant but should be inspected again in the field before being installed. Pipes should be inspected for the following defects:

1. Major Defects
   a. Uneven laps
   b. Variation from straight center line
   c. Variation from design shape
   d. Lack of rigidity
   e. Illegible brand
   f. Bruised, scaled or broken spelter coating
   g. Dents or bends that will affect the use or function of the pipe

2. Minor Defects
   a. Ragged or diagonal edges
   b. Loose or unevenly spaced rivets
   c. Poorly formed rivet heads
   d. Unfinished ends
   e. Dents or bends in the material that will not affect the use or function of the pipe

In general, a pipe is not rejected unless there is a major defect or five or more minor defects.

C. Culvert Installation

The foundation for the pipe should be constructed in such a manner that it will provide uniform bearing for the full length of the pipe. In order to accomplish this, the specifications provide for shaping the natural ground or bedding to fit the lower portion of the pipe, usually 15% of the outside diameter of the pipe. This should be checked with a template.

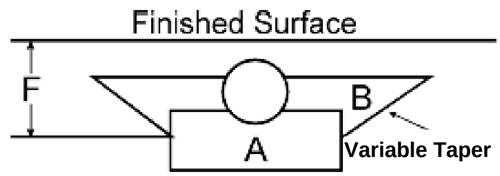
In cases where the pipe is placed in plastic soil and the pipe is within the frost penetration zone, treatments are provided to prevent heaving. The type of treatment, length of tapers, etc. will be shown in the typical sections.

It is the inspector's responsibility of the inspector to verify that treatments are properly staked and that tapers are properly constructed to the plan dimensions.

Note: Any changes (even seemingly minor alterations) to the design dimensions should be made only after consulting the Project Engineer and the District Soils Engineer.

Compaction of the embankment adjacent to the pipe shall be in accordance with 2105.3 E(4) of the specifications. This specification provides that, when the diameter of the pipe is 1.22 m (48") or less, the embankment for a distance of 20 m (50 feet)on each side of the pipe shall be compacted to a density of not less than 100% of the Maximum Density and, when the diameter of the pipe exceeds 1.22 m (48"), the 100% density requirement shall apply for a distance of 35 m (100 feet) on each side of the pipe. It is not necessary to make a density test for each layer compacted adjacent to a structure. Good visual inspection together with an occasional test to verify the inspectors judgment is sufficient.

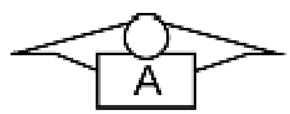
The inspector should familiarize himself with the requirements of 2501 of the specifications for the installation of pipe culverts and closely inspect the work to determine compliance with the specifications.



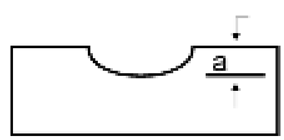
A = Class 5 bedding (Aggregate Bedding)
Required - moisture, density, gradation tests

B = Granular backfill Required - moisture, density, gradation tests

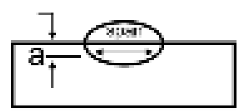
F = Average depth of frost penetration (furnished by District Soils Engineer)
Note: It is not necessary to make a gradation test of bedding or granular material for each installation. Tests should be made at the prescribed rate for each class of material. Moisture and density tests do not have to be made for each layer placed. Take only as many tests as are necessary and practical to document the work. Backfill (B) shall be placed in approximately equal layers simultaneously on both sides of the pipe.



Start tapers at average frost depth and taper to ground line using recommended taper.



Before placing pipe, shape bedding to fit lower portion of pipe.
a = 15% of outside Diameter of the pipe



For deformed pipe, a = 1/2 of the height from the bottom of the pipe to the elevation of the maximum span.

When the flow line of the pipe is at natural ground line, and the pipe is installed ahead of embankment construction, tapers of the granular backfill may be reversed as shown above.
Note: Check with template.

The required density for bedding, backfill and embankment to the top of the pipe is 100% relative density.

If aggregate bedding or backfill is exposed at ends of the pipe, seal with 12 inches of plastic soils.

5-692.430M CONVERSION FACTORS USED IN GRADING AND BASE WORK (METRIC)

Scope

The purpose of this section is to acquaint the inspector with the basic materials measurement conversions used in grading and base construction work. This section will also provide the method for calculating these conversions. A table of conversions is shown at the end of this section.

Conversion Calculation

Conversions have been established for both the Grading and Base items. The Grading conversions are measurement of materials in cubic meters at the borrow source (Bank Measure), in the hauling unit (Loose Volume) and the material placed in the embankment (Compacted or Placed Volume). The base conversions are generally metric tons (t), cubic meters (m^3) (Loose Volume - LV) and cubic meters (Compacted Volume - CV).

The standard gravel base conversions are calculated on the proctor density of 2160 kilograms (kg) per cubic meter (m^3). This proctor was chosen as it best represents the statewide average. Variations for lighter or heavier materials can be calculated on the basis of their proctors. However, this is only done when there will be significant quantities involved. The Grading and Base Office should be contacted when the non standard conversion is going to be used.

Note: When making any conversions for the purposes of measuring pay quantities, a Change Order must be prepared.

Gravel Base Conversion Calculations:

A. Cubic Meters (m^3) Loose Volume to metric tons (t). (This conversion uses the standard weight of gravel base Loose Volume which is 1680 kg/m^3).

Formula

$$\text{Cubic Meter (LV)} = \frac{\text{kg(LV)}}{\text{m}^3} \text{ x } \frac{\text{t}}{\text{1000 kg}} = \text{metric tons (t)}$$

$$1 \text{ m}^3 \text{ (LV)} = 1680 \text{ x } \frac{\text{1 (t)}}{\text{1000 kg}} = \text{metric tons (t)}$$

$$1 \text{ m}^3 \text{ (LV)} = \frac{1680}{1000} = 1.68 = 1.7 \text{ metric tons (t)}$$

Therefore:

Cubic Meter (m^3) (LV) = 1.7 metric tons (t)

B. Cubic meters (m^3) compacted volume to metric tons (t). (This conversion uses the average proctor for base material of 2160 kilograms (kg) per cubic meter (m^3).

Formula:

$$\text{Cubic Meter (CV)} = \frac{\text{kg (CV)}}{\text{m}^3} \times \frac{\text{t}}{1000\ \text{kg}} = \text{metric tons (t)}$$

$$1\ \text{m}^3\ \text{(CV)} = 2160\ (kg)\ x\ \frac{1\ \text{t}}{1000\ \text{kg}} = \text{metric tons (t)}$$

$$1\ \text{m}^3\ \text{(CV)} = \frac{2160}{1000} = 2.16 = 2.2\ \text{metric tons (t)}$$

Therefore:

1 Cubic Meter (m^3) (CV) = 2.2 metric tons (t)

C. Cubic Meter Compacted Volume to Cubic Meter Loose Volume. (Using the two relations developed in (A.) and (B.) of this section.)

1 m^3 (LV) = 1.7 metric tons (t)
1 m^3 (CV) = 2.2 metric tons (t)

$$\frac{1\ \text{m}^3\ \text{(CV)}}{1\ \text{m}^3\ \text{(LV)}} = \frac{2.2\ \text{metric tons (t)}}{1.7\ \text{metric tons (t)}} = 1.294 = 1.3$$

1.294 = 1.3

Therefore: 1 m^3 (CV) = 1.3 m^3 (LV)

Grading Conversion Calculations:

A. Cubic Meter Compacted Volume to Cubic Meter Loose Volume.

For grading soils, we have retained the same relationship between Loose Volume and Compacted Volume as calculated for base materials.

Therefore: 1 m^3 (CV) = 1.3 m^3 (LV).

B. Cubic Meter Compacted Volume to Cubic Meter Bank Measure.

The Bank Measure refers to material in the borrow pit in its natural state of compaction. For general application we have assigned material in the natural compaction state a relative density of 90% of proctor density.

Formula
Cubic Meter (Bank Measure) = 90% x 1 Cubic Meter (CV)

$$\frac{1\,\text{m}^3\ \text{(BM)}}{1\,\text{m}^3\ \text{(CV)}} = \frac{1.2\ \text{m}^3\ \text{(LV)}}{1.3\,\text{m}^3\ \text{(LV)}} = 0.923$$

0.923= 0.9

Therefore:

1 m^3 (BM) = 0.9 m^3 (CV)

OR

$$\frac{1\,\text{m}^3\ \text{(BM)}}{0.9} = \frac{0.9\ \text{m}^3\ \text{(CV)}}{0.9} = 1.11$$

1.11 = 1.1

Therefore:

1 m^3 (CV) = 1.1 m^3 (BM)

C. Cubic Meter Bank Measure to Cubic Meter Loose Volume.

Relationships established in section (A.) and (B.) are used to make this conversion.

1 m^3 (CV) = 1.3 m^3 (LV)
1 m^3 (CV) = 1.1 m^3 (BM)

Therefore:

1.1 m^3 (BM) = 1.3 m^3 (LV)

$$\frac{1.1\,\text{m}^3\ \text{(BM)}}{1.1} = \frac{1.3\ \text{m}^3\ \text{(LV)}}{1.1}$$

$$\frac{1.3}{1.1} = 1.181 = 1.2$$

Therefore:

$1\ m^3$ (BM) = $1.2\ m^3$ (LV)

Note: The grading conversions from Bank Measure to Compacted Volume and Loose Volume are based on the 90% relative density assumption for material in natural state of compaction. Calculations involving materials at a significant depth in the borrow area i.e. material with a thick layer of material inplace above it, should be made based on field test results. The Grading and Base Office should be contacted for assistance in making these determinations.

Conversion Tables:

A. Base Materials

1 metric ton (t) = $.595\ m^3$ (LV)

1 metric ton (t) = $.463\ m^3$ (CV)

$1\ m^3$ (LV) = 1.7 metric tons (t)

$1\ m^3$ (LV) = $.77\ m^3$ (CV)

$1\ m^3$ (CV) = 2.2 metric tons (t)

$1\ m^3$ (CV) = $1.3\ m^3$ (LV)

B. Grading Soils

$1\ m^3$ (CV) = $1.3\ m^3$ (LV)

$1\ m^3$ (CV) = $1.1\ m^3$ (BM)

$1\ m^3$ (LV) = $.83\ m^3$ (BM)

$1\ m^3$ (LV) = $.77\ m^3$ (CV)

$1\ m^3$ (BM) = $.90\ m^3$ (CV)

$1\ m^3$ (BM) = $1.2\ m^3$ (LV)

5-692.430E CONVERSION FACTORS USED IN GRADING AND BASE WORK (ENGLISH)

Scope

The purpose of this section is to acquaint the inspector with the basic materials measurement conversions used in grading and base construction work. This section will also provide the method for calculating these conversions. A table of conversions is shown at the end of this section.

Conversion Calculation

Conversions have been established for both the Grading and Base items. The Grading conversions are measurement of materials in cubic yards at the borrow source (Bank Measure), in the hauling unit (Loose Volume) and the material placed in the embankment (Compacted or Placed Volume). The base conversions are generally tons, cubic yards (yd^3) (Loose Volume - LV) and cubic yards placed (Compacted Volume - CV).

The standard gravel base conversions are calculated on the proctor density of 135 pounds per cubic foot. This proctor was chosen as it best represents the statewide average. Variations for lighter or heavier materials can be calculated on the basis of their proctors. However, this is only done when there will be significant quantities involved. The Grading and Base Office should be contacted when the non standard conversion is going to be used.

> **Note:** When making any conversions for the purposes of measuring pay quantities, a Change Order must be prepared.

Gravel Base Conversion Calculations

A. Tons to Cubic Yards Loose Volume. (This conversion uses the standard weight of sand Loose Volume which is 105 pounds per cubic foot).

Formula

$$\text{Cubic Yard (LV)} = \frac{\text{lbs.}}{\text{ft.}^3} \times \frac{27\ \text{ft.}^3}{\text{yd.}^3} \times \frac{\text{tons}}{2000\ \text{lbs.}} = \text{tons}$$

$$1\ \text{yd.}^3\ (\text{LV}) = \frac{105\text{lbs.}}{\text{ft.}^3} \times \frac{27\ \text{ft.}^3}{\text{yd.}^3} \times \frac{1\ \text{ton}}{2000\ \text{lbs.}} = \text{tons}$$

$$1\ \text{yd.}^3\ (\text{LV}) = \frac{105 \times 27}{2000} = \frac{2835}{2000} = 1.4175 = 1.4\ \text{tons}$$

Therefore:

1 Cubic Yard (LV) = 1.4 tons

B. Tons to Cubic Yards Compacted Volume. (This conversion uses the average proctor for base material of 135 pounds per cubic foot.)

Formula:

$$\text{Cubic Yard (CV)} = \frac{\text{lbs.}}{\text{ft.}^3}\ \text{(CV)} \times \frac{27\ \text{ft.}^3}{\text{yd}^3} \times \frac{\text{tons}}{2000\ \text{lbs.}} = \text{tons}$$

$$1\ \text{cu. yd. (CV)} = \frac{135\ \text{lbs.}}{\text{ft.}^3} \times \frac{27\ \text{ft.}^3}{\text{yd.}^3} \times \frac{1\ \text{ton}}{2000\ \text{lbs.}} = \text{tons}$$

$$1\ \text{cu. yd. (CV)} = \frac{135 \times 27}{2000} = \frac{3645}{2000} = 1.802 = 1.8\ \text{tons}$$

Therefore:

1 Cubic Yard (CV) = 1.8 tons

C. Cubic Yards Compacted Volume to Cubic Yards Loose Volume. (Using the two relations developed in (A.) and (B.) of this section.)

1 cu. yd. (LV) = 1.4 tons
1 cu. yd. (CV) = 1.8 tons

$$\frac{1\ \text{cu. yd. (CV)}}{1\ \text{cu. yd. (LV)}} = \frac{1.8\ \text{tons}}{1.4\ \text{tons}} = 1.285 = 1.3$$

Therefore: 1 Cubic Yard (CV) = 1.3 Cubic Yards (LV)

Grading Conversion Calculations

A. Cubic Yards Loose Volume to Cubic Yards Compacted Volume.

In grading we have retained the same relationship between Loose Volume and Compacted Volume as calculated for base materials.

Therefore: 1 Cubic Yard (CV) = 1.3 Cubic Yards (LV).

B. Cubic Yards Bank Measure to Cubic Yards Compacted Volume.

The Bank Measure refers to material in the borrow pit in its natural state of compaction. For general application we have assigned material in the natural compaction state a relative density of 90% of proctor density.

Formula

1 Cubic Yards (Bank Measure) = 90% x 1 Cubic Yard (CV)

$$\frac{1\,\text{yd.}^3\ (\text{BM})}{0.90} = 1\,\text{yd.}^3(\text{CV})$$

$$\frac{1}{0.9} = 1.111 = 1.1$$

Therefore:

1 Cubic Yard (CV) = 1.1 Cubic Yard (Bank Measure)

C. Cubic Yards Bank Measure to Cubic Yards Loose Volume.

Relationships established in section (A.) and (B.) are used to make this conversion.

(1) 1 yd.^3 (CV) = 1.3 yd.^3 (LV)
(2) 1 yd.^3 (CV) = 1.1 yd.^3 (BM)

Therefore:

1.1 yd.^3 (BM) = 1.3 yd.^3 (LV)

$$\frac{1.1\,\text{yd.}^3(\text{BM})}{1.1} = \frac{1.3\,\text{yd.}^3(\text{LV})}{1.1}$$

$$1 = \frac{1.3}{1.1} = 1.181 = 1.2$$

Therefore:

1 Cubic Yard (BM) = 1.2 Cubic Yards (LV)

Note: The grading conversions from Bank Measure to Compacted Volume and Loose Volume are based on the 90% relative density assumption for material in natural state of compaction. Calculations involving materials at a significant depth in the borrow area i.e. material with a thick layer of material inplace above it, should be made based on field test results. The Grading and Base Office should be contacted for assistance in making these determinations.

Conversion Tables:

A. Base Materials

1 ton = .714 yd^3 (LV)

1 ton = .550 yd^3 (CV)

1 yd^3 (LV) = 1.4 ton
1 yd^3 (LV) = .77 yd^3 (CV)

1 yd^3 (CV) = 1.8 ton
1 yd^3 (CV) = 1.3 yd^3 (LV)

B. Grading

1 yd^3 (CV) = 1.3 yd^3 (LV)

1 yd^3 (CV) = 1.1 yd^3 (BM)

1 yd^3 (LV) = .83 yd^3 (BM)

1 yd^3 (LV) = .77 yd^3 (CV)

1 yd^3 (BM) = .90 yd^3 (CV)

1 yd^3 (BM) = 1.2 yd^3 (LV)

5-692.500
TREATMENT AND STABILIZATION OF SOILS AND AGGREGATES

5-692.515 USE OF CALCIUM CHLORIDE FOR DUST CONTROL

Calcium chloride (3911) is frequently used for dust control. It is used on roads under construction, on haul roads used during construction or on unsurfaced roads where heavy dust is a nuisance or a pollution problem. It “lays dust”.

The calcium chloride is a deliquescent material, holding moisture from evaporation and so changing the roads’ surface from wind-blown swirling materials to moistened and stable riding surface.

Calcium chloride ($CaC1_2$) can be applied either in a solid or liquid form. The liquid calcium chloride shall contain a minimum of 38 percent, by mass (weight), anhydrous $CaC1_2$. Andydrous $CaC1_2$ is produced by mixing water and a given amount of solid $CaC1_2$.

The solid $CaC1_2$ comes in two types:

Type I - Flake = 77% $CaC1_2$
Type II - Pellet = 94% $CaC1_2$

APPLICATION RATES FOR DUST CONTROL - Metric

	Type I	Type II	(*) 38% Solution
Initial Use	0.5kg/m^2	0.4kg/m^2	1.0 liter/m^2 (Type I or II)
Additional Use	0.25kg/m^2	0.2kg/m^2	0.5 liter/m^2 (Type I or II)

(*) add 0.6 kg/liter of Type I for a 38% solution.
add 0.5kg/liter of Type II for a 38% solution.

Note: a 38% solution liter will weigh approximately 1.3 kg.

APPLICATION RATES FOR DUST CONTROL - English

	Type I	Type II	(*) 38% Solution
Initial Use	1.0 lbs./sq.yd.	0.8 lbs./sq.yd	0.2 gals./sq.yd. (Type I or II)
Additional Use	0.5 lbs./sq.yd.	0.4 lbs./sq.yd	0.1 gals./sq.yd. (Type I or II)

(*) add 5.6 lbs./gallon of Type I for a 38% solution.
add 4.7 lbs./gallon of Type II for a 38% solution.

Note: a 38% solution gallon will weigh approximately 11.6 lbs.

5-692.521 USE OF LIME TO DRY SOIL

Under certain conditions, drying of fine grained soils by treating them with lime is more economical than by scarifying and aerating by mechanical methods. Lime reacts with clay particles in the soil to produce decreased plasticity, improved work ability, and increased strength and stability. This process works best when the soils are reactive. Soils with a minimum clay content (.002 mm) of approximately ten percent and a plasticity Index greater than ten respond most favorable. Soils with over two percent organic matter will probably show very little increase in strength.

There are two lime products which may be used:

1. Quicklime is calcined calcium carbonate or calcium oxide (CaO) is highly reactive, especially when mixed with water.
2. Hydrated lime is quick lime that has had part of its water demand satisfied by carefully adding water in the slaking process until it is essentially calcium hydroxide ($Ca(OH)_2$).

Of the two, hydrated lime is the most desirable. The amount of lime required depends on the soil type and moisture content. In most cases, less than 1% hydrated lime is sufficient if it is properly spread and mixed with the soil. In no case should more than 2% lime be used. As a rule of thumb, for most soils and for a 150 mm (6 inch) layer, one percent lime corresponds to about 2.7 kg/m^2 (5 lb./sq. yd.). Quicklime may be substituted for hydrated lime on the basis of 0.77% quicklime being equal to 1.0% hydrated lime. However, because of the hazards involved, more stringent safety precautions will be necessary if the use of quicklime is approved. Recommendations of the Industry on safety rules and first aid procedures should be followed. This includes the use of special clothing, protective cream, and eyes, mouth and nose protection. Hot, humid weather tends to increase the effect of lime on the worker's skin.

The contractor may request using lime at his expense. Lime is not permitted without the approval of the project engineer. A change order stating the application rate and other conditions should be prepared.

There may be times when the Department wishes to use hydrated lime. The District Soils or Materials Engineer should be consulted in making decisions on the use of lime. Lime should be used only after it is demonstrated that the soil cannot be dried by conventional methods due to excessive moisture and poor drying weather. A supplemental agreement will have to be prepared, with the concurrence of the Assistant District Engineer, to pay for the lime and work involved in accordance with the provisions of the specification pertaining to extra work. In negotiating the supplemental agreement, it should be realized that the cost of placing and compacting the soil is already included in the bid price for excavation. The cost of the lime, spreading and mixing are extra. However, the use of lime should reduce the work normally required to dry the soil.

The construction involves scarification, lime spreading, mixing and compaction. Scarifying before spreading the lime helps to prevent loss due to wind and rain, particularly if mixing is not started immediately. Application of lime should be full width across the grade. Lime should not be spread under windy conditions because of excessive dusting. To prevent wind loss, the lime shall be mixed into the soil immediately after spreading. Self-unloading bulk tanker trucks are most efficient for transporting and spreading lime, since re-handling is not necessary. Tailgate spreading should not be allowed. Thorough mixing is essential to distribute the lime uniformly throughout the soil to proper depth and width - Disc harrows may be adequate for mixing, although rotary mixers are preferred for heavier soils. After satisfactory moisture and soil conditions are attained, the material can be compacted as specified. Sheepsfoot rollers should be used for initial compaction. Final rolling with a pneumatic roller will help to seal the subgrade and cause it to shed rain water, thereby eliminating construction delays.

When lime is used as a drying aid, it will be necessary to establish a new moisture density relationship for the soil plus the lime. The optimum moisture should be slightly higher and the maximum density should be slightly lower than for the soil without lime.

5-692.580 BITUMINOUS STABILIZED SUBGRADE AND BASE

5-692.581 SAMPLING

A. Bituminous materials shall be sampled in accordance with the procedures described in the Minnesota Department of Transportation "Bituminous Manual".

B. Moisture Samples
   1. When asphalt emulsion is used, obtain a sample from the treated material at the time the mixture is ready for compaction.
   2. When other bituminous materials are used, obtain a sample before the bituminous material is added.
   3. The minimum rate of sampling for relative moisture is one per 1000 m (1500 ft.) for bituminous stabilized subgrade and one per 350 m^3 (750 ton) for bituminous treated base.

C. "One Point Density"
At each location where a field density test will be made, a sample shall be obtained for the moisture at the conclusion of mixing operations. To minimize loss by evaporation, select the sample by direct sampling rather than by quartering. Samples shall weigh about 5 kg (10 lbs.) and shall be placed in an air tight container until the test is made.

5-692.582 MOISTURE TEST

A. When asphalt emulsion is used, the total fluid content shall be determined by the method described in 5-692.245 except that the Calcium Carbide Moisture Tester shall not be used. The sample shall be dried to a constant weight in an oven or over an open burner at a temperature not to exceed 110° C (230° F). If the sample is dried over an open burner, a sand bath must be used and the heat applied cautiously in order to keep the sample under 110° C (230° F). A sand bath is constructed by placing a 25 mm (1”) to 40 mm (1 ½”) layer of sand in a metal pan. The sample, in the drying pan, is then placed on the sand bed to dry. The total fluid content is compared to the Optimum Moisture of untreated base aggregate or soils to determine the relative moisture of the mixture at time of compaction.

Example:
Total fluid content of the treated base aggregate at time of spreading and compacting = 10.5%

Optimum Moisture of the untreated base aggregate = 11.0%

$$\text{Relative Moisture of the mixture (\%)} = \frac{10.5}{11.0} \times 100$$

Relative Moisture of the mixture = 95%

5-692.583 ONE POINT DENSITY TEST PROCEDURE

A. Apparatus - See paragraph B, 1 through 9 of 5-692.222.

B. Test Procedure
The test should be made as soon as possible after the sample is obtained.

Step 1. Weigh the mold and base plate on the platform scale to the nearest gram. (Do not include the weight of the collar). Record the weight.

Step 2. Place the assembled mold, including collar, on the concrete compaction base.

Step 3. Place enough of the sample into the mold for one layer.

Note: The mold is filled with 3 equal layers of compacted material. The top layer, after compaction, should be about 15 mm (½”) over the top of the mold when the collar is removed.

Step 4. Compact the loose material with 25 blows from the rammer dropped from 300 mm (12”) above the material. Distribute the blows evenly.

Step 5. Repeat step 3 and 4 until 3 layers are inplace.

Step 6. Remove the collar and trim the compacted material with the butcher knife until it is even with the top of the mold (check with the spatula). Remove any stones dislodged by trimming and fill the holes by carefully pressing finer material into place. Trim around the stones that are at least ½ buried and solidly seated.

Step 7. Clean the loose material from the mold and base plate and weigh it to the nearest gram on the platform scale. Record the weight.

Step 8. Remove the mold from the base plate and loosen the locking device so that the compacted material can be removed from the mold.

Step 9. Select a representative sample for a moisture test to determine the total fluid content of the material. Conduct the test according to the Burner Method in 5-692.245 using a sand bath to distribute the heat. Do not use the "Speedy" moisture method.

Step 10. Calculate the One Point Density.

Example: Wet wt. of mixture, mold and base plate = 7.493 kg (16.52 lb.)

Wt. of mold and base plate = 5.625 kg (12.40 lb.)

Volume of mold = approximately 1/1060 m^3 (1/30 $ft.^3$)

% moisture dry wt. = 9.8% (see 5-692.245C for example)

a. (Metric) Wet Density = (7.493 - 5.625) 1059.43 = 1979 kg/m^3

$$\text{(Metric) Dry Density} = \frac{\text{wet density}}{1 + \frac{\%\text{ moisture}}{100}} = \frac{1979}{1.098} = 1802\text{ kg / m}^3$$

b. (English) Wet Density = (16.52 – 12.40) 30 = 123.6 lbs./ $ft.^3$

$$\text{(English) Dry Density} = \frac{\text{wet density}}{1 + \frac{\%\text{ moisture}}{100}} = \frac{123.6}{1.098} = 112.6\text{ lbs./ft.}^3$$

Step 11. When the contractor is finished compacting the treated material, perform a Field Density Test (5-692.246) at the same location that the sample for the One Point Density was obtained.

Step 12. Determine the Relative Density of the inplace compacted treated base or subgrade.

Example: One Point Density = 1802 kg/m^3 (112.6 lb./ ft.^{3})
Field Density = 1852 kg/m^3 (115.6 lb./ ft.^{3})

a. (Metric) Relative Density = $\frac{1852}{1802}$ x 100

Relative Density = 103%

b. (English) Relative Density = $\frac{115.6}{112.6}$ x 100

Relative Density = 103%

5-692.600
SOIL CLASSIFICATION INTRODUCTION

5-692.600 SOIL CLASSIFICATION INTRODUCTION

In present day soil engineering practice as applied to various fields of engineering such as highways, airports, dams, foundations, and the like, there are several different methods of soil classification in use. Most of them attempt to classify soils into groups on the basis of their engineering properties; that is, the manner in which they will perform as part of an engineering structure under a given set of conditions. The purpose of this is largely to aid the design engineer in deciding how the soil is apt to behave when it is put into one of these structures or a structure is placed on top of it. The procedures in classifying soils involves a number of tests which are mostly made in the Laboratory.

In highway construction, soil is used both in the road structure (i.e. embankments, cut slopes, roadbed in both cuts and fills) and as a foundation to support the embankments, culverts, and bridges. Soil is, therefore, a basic element of the highway, and as such it is necessary that the persons who work with it and use it be able to identify the soil types.

In this section we will deal with the two classification systems used by Mn/DOT. The textural classification which is mainly used as a working tool for field soil selection and the AASHTO classification which is used exclusively for engineering design.

Since we use both systems, a section showing the interrelation of the two systems is also provided.

5-692.601 SOIL IDENTIFICATION

The first objective should be to identify and describe soils in such a way that others will understand exactly what is meant; that is, if a silt loam is mentioned, that name should convey essentially the same meaning to each person. Other terms may elaborate on it and describe it more fully. The complete description would then convey a very definite picture of that particular soil.

The following sections are devoted to classifying and describing soil materials in detail. An understanding of the classification procedures will aid the engineer and inspector in the field in identifying soils, in evaluating the engineering properties, in applying better soil selection and in performing the field test more accurately.

5-692.602 PEDOLOGICAL CLASSIFICATION

The more common characteristics of soils by which they may be described include the following:

Texture	Consistency
Color	Compactness
Structure	Cementation

These characteristics are discernible in the field, and, except for the exact texture, they do not have to be determined by laboratory analysis. They do not describe the engineering properties as such, but they are related to such properties as capillarity, compactability, expansion, elasticity, density, supporting power, and others.

The engineering properties associated with soils have been used for classification and are the basis of the AASHTO system. The AASHTO system uses the engineering properties of elasticity, expansion and load bearing capacity based on actual field use along with exact texture as to basis for classification.

5-692.603 PRIMARY CLASSIFIER (TEXTURE)

A. DEFINITION OF TEXTURES

Texture is a term used to indicate the size of individual particles in a given soil mass and the proportions of each size present. Most natural soil masses consist of a combination of many grain or particle sizes. The distribution of particle sizes and the relative predominance of fine or coarse grains imparts to the soil a distinctive appearance and “feel”, which is called texture. The textural terms used to describe soils express the average effect of all the grain sizes or the effect of the predominant group of particles. Texture is the most common term used to identify soils.

B. SOIL COMPONENTS

The principal particle sizes of soil are:

1. Gravel
2. Sand
3. Silt
4. Clay

All soils are made up of one or all of these distinct components in combination. Each component has a definite grain size range and characteristic reaction in the soil mass. The soil particle sizes and their quantity distribution throughout the soil mass are important factors which influence soil properties and performance.

C. GRAIN SIZES OF SOIL

The grain size ranges for the above soil components are described in the following table:

Particle Size	Diameter in Millimeters	Corresponding U.S. Standard Sieve Sizes	
		Passing	Retained On
Gravel	75 to 2.0	75 mm (3”)	2 mm (No. 10)
Coarse Sand	2.0 to 0.425	2 mm (No. 10)	425 Φm (No. 40)
Fine Sand	0.425 to 0.075	425 Φm (No. 40)	75 Φm (No. 200)
Silt	0.075 to 0.002	Cannot be separated by sieving. Determined by settling velocity in soil-water suspension	
Clay	Smaller than 0.002		
Colloidal Clay	Smaller than 0.001		

D. LABORATORY DETERMINATION OF TEXTURE:

Since most all soils are made up of a combination of the above particle sizes, it is necessary to separate these particles into the different grain size groups to determine the exact classification. This is done in the laboratory by mechanical analysis.

The percentages of gravel and sand in a representative soil sample are determined by shaking it through the required sieve sizes. The percentages of smaller size particles, silt and clay, both of which pass the 75□m sieve (No. 200), are determined by hydrometer analysis. This involves measuring the settling velocity of these particles when the sample is thoroughly dispersed in a soil-water suspension. Since larger, heavier particles settle out of suspension more rapidly, the time rate of settlement provides a measure of the relative size of fine soil grains. Thus as the soil grains continue to settle with elapsed time, the specific gravity of the soil-water suspension becomes lighter. A graduated hydrometer immersed in the suspension at increasing time intervals measures the change in specific gravity. By using the hydrometer readings in the proper formula, the percentages of silt and clay in the soil sample can be calculated.

Thus knowing the percentages of each grain size group in the sample, the soil can be assigned a definite textural classification dependent upon the various amount of sand, silt and clay. The textural classification of soils is determined by using the triaxial chart, (see Figure 1 5-692.603).

The basic concept for this textural classification was originated by the United States Bureau of Chemistry and Soils. It defines the main soil classes in relation to their percentage of sand, silt, and clay. Stone and gravel particles larger than the sand size (2mm) [No. 10] sieve ordinarily do not change the basic soil classification. Soils containing in excess of 25% gravel particles are, however, generally termed gravelly or stony soils.

The textural names of the soils are designed to tell as much as possible about the soil in one word or a combination of two or three words. This makes the definitions of soil texture important. With texture given, approximations and estimates of many soil properties can be made, such as bearing value, water-holding capacity, susceptibility to frost heave, maximum dry density and optimum moisture content.

The triaxial chart places the soil textures into three main groups on the basis of clay content. The three main groups are then subdivided further.

1. Soils Containing Less than 20% Clay.
   - Sand
   - Loamy Sand
   - Sandy Loam
   - Loam
   - Silt Loam
   - Silt
2. Soils Containing From 20% to 30% Clay.
   - Sandy Clay Loam
   - Clay Loam
   - Silty Clay Loam
3. Soils Containing 30% or More Clay.
   - Sandy Clay
   - Clay
   - Silty Clay

Table A 5-692.603 shows the soil textures with their gradation limits determined by laboratory mechanical analysis.

E. FIELD DETERMINATION OF TEXTURE:

Engineers and inspectors must be able to determine textural classification of soils within a reasonable degree of accuracy in the field in order to perform the duties of soil selection and construction monitoring.

Complete mechanical analysis tests on soil generally cannot be made in the field laboratory. Only the gradation of the coarse fraction (plus 75 Φm sieve) (No. 200) of the soil sample can be determined in the field by sieve analysis. The fine fraction, which consists of silt and clay particles must be determined in the laboratory by a hydrometer analysis.

Identification of soil texture in the field must therefore be accomplished by the feel and appearance of the soil mass. This requires training and experience. It is one of the most important functions of field soils inspection. Soil identification with reasonable accuracy is essential when performing soil selection and in performing density and moisture control tests on grading.

Soil is classified in the field by using two methods: 1.) forming a cast in the hand, 2.) by pressing or rubbing a moist sample between the thumb and index finger to form a thin ribbon until it breaks under its own weight in a horizontal position. The length of the ribbon is relative to the percent clay in the soil (see Figure 1 5-692.603). These two methods constitute the major field identification procedure tests used to judge soil texture.

In classifying soils, it is important that the soil contains a normal amount of moisture. A normal amount in general is when the soil feels moist to the touch and yet have workability. Ribboning for identification is to be done when the soil moisture is such that the soil sample can be worked by the fingers but does provide some resistance to ribboning. Ribbons should be about 10mm (1/2") wide and about 3mm (1/8") thick for best results. It may be difficult at times to positively classify soils by these methods. With practice, experience, and by comparison of soil samples with specimens classified by laboratory analysis, it is possible to become reasonably proficient.

The following descriptions of the soil textural classes are designed to assist the inspector in identifying them in the field. The main soil classes shown in the textural chart are described as well as variations which are likely to be encountered.

Remember that gravel, sand, and pure silt are non-plastic materials. Clay is plastic and cohesive. Sand and silt will become more or less plastic when mixed with various proportions of clay.

1. GRAVEL (G)
   Gravel is a combination of stones between a maximum size of 75mm (3") and minimum diameter of a 2mm (No. 10) sieve. Fine Gravel (FG) is a predominance of stones between the 9.5mm (3/8") screen and the 2mm (No. 10) sieve. Gravel is easily identified by visual inspection.

2. SAND (S)
   Sand is material which passes the 2mm (No. 10) sieve 100%. It contains less than 10% silt performing and clay combined (minus 75Φm [No. 200] sieve size particles). It therefore contains 90% or more of sand size particles).

   Sand is loose and granular. The individual grains can readily be seen and felt. It is non-plastic and therefore cannot be pressed into soil ribbons. If squeezed into a cast in the hand when dry, it will fall apart when the pressure is released. Squeezed when moist, it will form a cast that will hold its shape when the pressure is released but will crumble when touched or jarred slightly.

   Coarse Sand (CrS) is sand in which the predominant particle size is between the 2mm (No. 10) sieve and the 425Φm (No. 40) sieve.

   Fine Sand (FS) is sand in which the predominant particle size is between the 425Φm (No. 40) sieve and the 75Φm (No. 200) sieve.

   Very Fine Sand (VFS) is sand in which practically all particles are close to the 75Φm (No. 200) sieve size. Some very fine sand particles will pass the 75Φm (No. 200) sieve. At times it is difficult in the field to distinguish between very fine sand and silt.

The plain term Sand (S) is applied when a sample is well graded, containing approximately equal proportions of coarse sand and fine sand.

3. SAND AND GRAVEL (S&G)
Sand and gravel is a mixture of the sand group and gravel group, and is identified by visual inspection. Variations might include the following:

Sand and Fine Gravel (S & FG)
Coarse Sand and Gravel (CrS & G)
Coarse Sand and Fine Gravel (CrS & FG)

4. LOAMY SAND (LS)
Loamy Sand passes the 2mm (No. 10) sieve 100%. It contains from 10% to 20% of fine-grained silt and clay combined (minus 75Φm [No. 200] sieve size particles). It therefore contains from 80% to 90% of the particle sizes called sand.

Loamy Sand is loose and granular. The individual grains can readily be seen and felt. It appears dirty when compared to the classification of sand, due to the higher silt and clay content.

Loamy Sand is non-plastic and therefore cannot be pressed into soil ribbons. Squeezed into a lump in the hand when moist, it will form a cast that will hold its shape when the pressure is released. The cast will not only withstand careful handling but some jarring as well without crumbling. This stability of the moist cast differentiates loamy sand from clean sand.

Loamy Sand can be further classed as coarse, fine, or very fine, the proper term depending on the proportions of different sizes of sand particles present.

Loamy Coarse Sand (LCrS)
Loamy Fine Sand (LFS)
Loamy Very Fine Sand (LVFS)

The plain term Loamy Sand (LS) is used when the material is well graded, containing approximately equal proportions of coarse sand and fine sand. The word “loamy” is placed first since these soils are predominantly sands.

5. SANDY LOAM (SL)
Sandy Loam contains from 20% to 50% silt and clay combined (minus 75Φm [No. 200] sieve size particles) but less than 20% clay. It may contain from 0 to 50% silt and 0 to 20% clay. It must always contain 50% or more sand grains to be classified as Sandy Loam.

Sandy Loam is the first soil of the textural classification which may be termed plastic. When moist, it therefore may be pressed into thin ribbons between the thumb and index finger. Since it contains much sand, the individual sand grains can readily be seen and felt. It contains enough silt and possibly some clay to make it somewhat coherent or stable. Sandy Loam is further qualified as non-plastic, slightly plastic or plastic. This difference, important in field work, is explained as follows:

Slightly plastic Sandy Loam (sl.pl.SL) generally contains from 0 to 10% clay. It may form a thin ribbon from 0 to 19mm (3/4") in length beyond the tip of the thumb and index finger before breaking under its own weight. The 0 length is more or less the sticking together of the sand grains in a pat when pressed in the fingers rather than the forming of any definite ribbon. It occurs when the clay content approaches zero. As the clay increases to 10%, the ribbon becomes longer up to approximately 19mm (3/4").

Plastic Sandy Loam (pl.SL) contains from approximately 10% to 20% clay and thus is more plastic or cohesive. It will press into ribbons from 19mm (3/4") to 37.5mm (1 1/2") in length as the clay content increases before breaking under its own weight.

Sandy Loam is further classified according to the proportions of different sizes of sand particles present, such as:

slightly plastic Coarse Sandy Loam (sl pl CrSL)
plastic Fine Sandy Loam (pl FSL)
plastic Very Fine Sandy Loam (pl VFSL)

The word "sandy" is placed first since these soils are predominantly loams.

6. LOAM (L)

The term "loam" for engineering purposes generally means a combination of sand, silt, and clay. However, in the triangular soil chart, it indicates a soil with definite proportions of sand, silt, and clay.

Loam contains more than 50% silt and clay combined (minus 75µm [No. 200] sieve size particles). It contains from 30% to 50% sand, 30% to 50% silt, and 0 to 20% clay. It is thus a relatively even mixture of sand and silt with less than 20% clay.

Loam is a mellow soil. It has a somewhat gritty feel and yet smoother feel than sandy loam, since most of the sand particles ordinarily consist of fine sand. When moist, it will form a ribbon approximately 5mm (1/4") to 37.5mm (1 1/2") in length and somewhat thinner and stronger than can be formed with sandy loam. The word "loam" is commonly used in agriculture as a term to describe topsoil containing black organic matter, which is easily worked and will support plant growth. However, loam, in engineering terminology, means soil of any color as long as it contains the specified proportions of sand, silt and clay.

7. SILT LOAM (SiL) and SILT (Si)
Silt Loam contains from 50% to 80% silt, 0 to 50% sand, and 0 to 20% clay. It must always contain 50% or more of silt particles to be classified as Silt Loam.

Silt contains from 80% to 100% silt, 0 to 20% sand, and 0 to 20% clay.

Silt Loam and Silt have a very fine grain structure. These materials have little or no plasticity. In a dry condition these materials may appear quite cloddy, but the lumps can be readily broken up. The material will feel soft and floury. When in a moist condition, the material will have a smooth and slippery feel and a velvety appearance. Depending on the clay content, these materials may be ribboned. Silt loam may ribbon up to 37.5mm (1 1/2") in length (slightly plastic, 0-19mm [0-3/4"] and plastic 19mm to 37.5mm [3/4" to 1 1/2"]. Silts will not press into a continuous unbroken ribbon but rather into shorter, crumbly, dull appearing segments. These segments may reach lengths up to 10 mm (1/2").

In its natural state in the ground, silt loam and silt are frequently very wet. This is due to their capillary affinity for water. In this condition it runs together and puddles easily when shaken.

All of the above soil classes from 1 through 7 are in the same grouping as they all contain less than 20% clay. They either will not ribbon because of their non-plastic, granular structure or will ribbon into lengths up to 37.5mm (1 1/2") due to the clay content.

8. CLAY LOAM (CL)
Clay Loam contains from 20% to 50% sand, 20% to 50% silt, and 20% to 30% clay. It is a fine textured soil and uniform in structure as indicated by its percentage composition of sand, silt and clay.

The dry natural soil breaks up into hard clods or lumps, which are difficult to pulverize. When moist, it will form a thin ribbon from 37.5mm (1 1/2") to 62.5mm (2 1/2") in length before breaking under its own weight. When it is thus ribboned between the thumb and index finger, it offers moderate resistance to deformation; that is, it requires considerable pressure to ribbon.

9. SILTY CLAY LOAM (SiCL)
Silty Clay Loam contains from 50% to 80% silt, 0 to 30% sand, and 20% to 30% clay. The largest percentage of particles are therefore of silt size.

Silty Clay Loam is also a fine textured soil and when dry will form hard clods or lumps. When moist, it will ribbon into length from 37.5mm (1 1/2") to 62.5mm (2 1/2") without breaking. When it is thus pressed between the thumb and index finger it does not offer as much resistance to deformation as clay loam. In other words, it feels softer. At normal moisture content, it feels slippery or "smeary" due to `the high silt content. When smeared in a thin layer on the inside of the thumb, it presents a dull appearance in comparison to clay or clay loam which is shiny.

Silty Clay Loam is usually found in the form of soil pockets when the natural formation consists of clay loam glacial till.

10. SANDY CLAY LOAM (SCL)
Sandy Clay Loam contains from 50% to 80% sand, 0 to 30% silt, and 20% to 30% clay. The largest percentage of particles are therefore sand. This gives it a gritty feel in comparison to the smooth, slippery feel of Silty Clay Loam.

Due to its high sand content, the sand particles can readily be seen and felt. In spite of its sandy structure, it is plastic and will form ribbons from 37.5mm (1 1/2”) to 62.5mm (2 1/2”) in length.

Sandy Clay Loam is found in the natural state only occasionally. When soils as plastic as this were geologically formed, the finer grained particles of silt and clay pre-dominated.

The three soil classes above, numbered 8 through 10, are in the second group of soils. They are similar as they all contain between 20% and 30% clay. Consequently, in field identification, they will form ribbons from 37.5mm (1 1/2”) to 62.5mm (2 1/2”) in length, and feel silty or sandy depending on the predominance of silt or sand particles. Clay Loam feels more even textured, neither silty or sandy, because of fairly equal distribution of silt and sand.

11. CLAY(C)
Clay contains from 30% to 100% clay, 0 to 50% silt, and 0 to 50% sand. It is very fine textured soil and very plastic.

When dry, clay forms very hard clods or lumps which are extremely difficult to pulverize. When moist, it will form a long, thin, flexible ribbon 62.5mm (2 1/2”) or more in length. When it is thus pressed between the thumb and index finger, it offers marked resistance to deformation; that is, it requires a great deal of finger pressure. Clay can be rolled into very thin threads. When smeared in a thin layer on the inside of the thumb, it presents a smooth, shiny surface.

12. SILTY CLAY (SiC)
Silty Clay contains from 30% to 50% clay, 50% to 70% silt, and 0 to 20% sand. It is very plastic and yet feels smooth and slippery. When moist, it will form a long, thin ribbon 62.5mm (2 1/2”) or more in length. The sand it contains, if any, is usually very fine and can not easily be detected in the soil mass. It is stiff like clay and requires a great deal of finger pressure to ribbon out.

Silty Clay in a natural soil condition may be said to have the appearance and smoothness of butter. It is normally encountered as soil pockets rather than the general soil mass.

13. SANDY CLAY (SC)
Sandy Clay contains from 30% to 50% clay, 50% to 70% sand, and 0 to 20% silt. The largest percentage of particles are of sand size and therefore the sand can readily be seen and felt. It is very plastic and yet feels gritty because of the high sand content.

When moist, it will form a long, flexible ribbon 62.5mm (2 1/2”) or more in length. It is stiff like clay and requires a good deal of finger pressure to ribbon out.

Sandy Clay is even more rare than sandy clay loam in the natural state and therefore is very seldom encountered.

The last three soil classes, numbered 11 through 13, are in the third group of soils. They are similar as they all contain 30% or more clay. In field identification, they will form ribbons 50mm or more in length because of this similarity. The most common of the three is clay when found in the natural state.

When identifying textural soil classification in the field by ribboning the soil mass between the thumb and index finger, it should be recognized that the length of ribbon designated in the foregoing descriptions does not always indicate exact classification. As an example, let us say that, by laboratory mechanical analysis, a soil contains 28% clay and is classified as clay loam. When identified in the field, it may ribbon to a length of 75mm (3”) instead of between 37.5mm (1 1/2”) and 62.5mm (2 1/2”) and thus be called clay. The difference could be in the plasticity of the clay or other inherent characteristics of the soil. Ribbon lengths are empirical, having been established from experience and observation, so may not reveal true classification in all cases. This is most noticeable where soils are border line between one classification and another. However, when so closely related in texture, they will react similarly when used for construction. It is fundamentally important for the inspector to be able to distinguish between the main soil classes when selecting soils and performing road tests. To fulfill this objective, ribboning and feeling soils provides the most practical means to quickly identify them in the field. For this reason, the method has merit even though not always exact.

By the triangular chart, soils are established into three main groups on the basis of clay content. Clay is the most active ingredient of the component parts of soil. The addition of clay changes the soil characteristics rapidly. The percentage of sand and gradation of the sand particles also have a marked effect upon soil tests. Thus, when the sand is mostly fine sand, or coarse sand, or a relatively even mixture of fine and coarse sand with possibly the addition of some gravel sizes, the results of such tests as maximum dry density and optimum moisture content are changed.

It should be noted that soil must contain 50% or more of sand particles to be classified in the sandy soil categories at the left side of the chart.

Likewise, soil must contain 50% or more of silt particles to be in the silty soil classes on the right side. When sand and silt are reasonably even in distribution, the uniform textured clayey soils in the center of the chart - loam, clay loam and clay - are obtained.

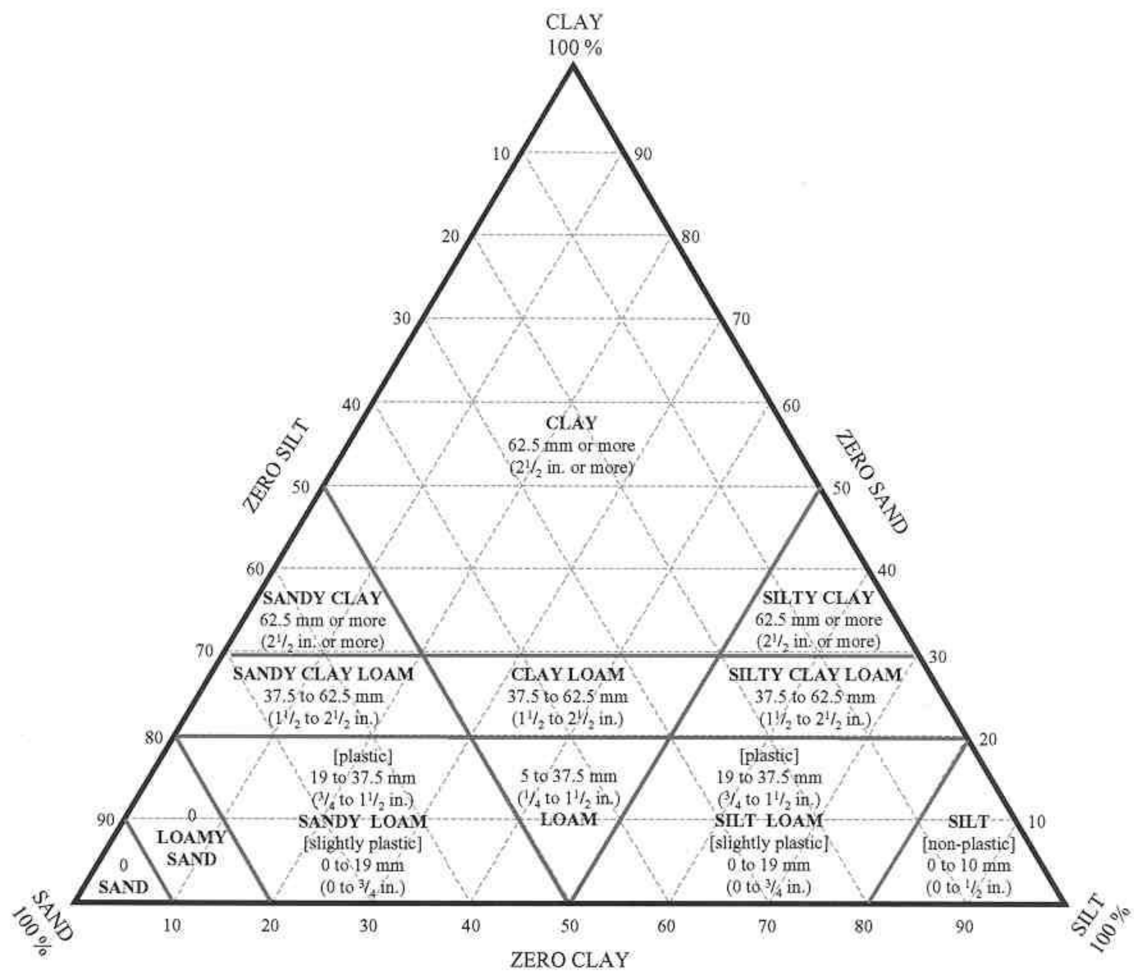
F. FEEL AND APPEARANCE OF SOIL MASS

CLAY – marked resitance to ribbon – roll to thin thread – shiny when smeared
SANDY CLAY – highly plastic – 50 to 70% sand – gritty – rarely encountered
SILTY CLAY – less resistance to ribbon than clay loam – slippery and soft
SANDY CLAY LOAM – gritty feel – sand particles easily seen and felt – uncommon
CLAY LOAM – fine textures – uniform and structure – moderate resistance to ribbon
SILTY CLAY LOAM – less resistance than clay loam – slippery – smeary – dull when smeared
SANDY LOAM – slightly plastic to plastic – sand grains seen and felt
LOAM – mellow – somewhat gritty but smoother than sandy loam
SILT LOAM – smooth, slippery or velvety – cloddy when dry – easily pulverized
SILT – smooth, powdery, velvety
LOAM SAND – will form a cast when wet – will stand light jarring
SAND – will form a cast when wet – crumbles easily

(See Fig. 1 5-692.603)

THE TRIAXIAL CHART

MAIN SOIL CLASSES SHOWING LENGTH TO WHICH
SOIL CAN BE RIBBONED AND THEIR PERCENTAGE
COMPOSITION OF SAND, SILT, AND CLAY



GRAIN SIZE

SAND ---------- Particle Diameter from 2.0 mm (# 10 Sieve) to 0.075 mm (# 200 Sieve)

SILT ------------ Particle Diameter from 0.075 mm (# 200 Sieve) to 0.002 mm

CLAY ---------- Particle Diameter below 0.002 mm

Fig. 1 5-692.603 (Triangular Chart)

GRADATION LIMIT OF TEXTURAL SOILS GROUP						
Soil Class	**Gravel %**	**Coarse Sand %**	**Fine Sand %**	**Silt & Clay %**	**Silt %**	**Clay %**
GROUP 1						
Gravel	90 to 100			0 to 10		0 to 10
Sand & Gravel	25 to 90			0 to 10		0 to 10
Coarse Sand	0 to 25	50 to 100		0 to 10		0 to 10
Sand	0 to 25	0 to 50	0 to 50	0 to 10		0 to 10
Fine Sand	0 to 25		50 to 100	0 to 10		0 to 10
Loamy Sand & Gravel	25 to 50	0 to 50	0 to 50	10 to 20		0 to 20
Loamy Coarse Sand	0 to 25	50 to 90		10 to 20		0 to 20
Loamy Sand	0 to 25	0 to 50	0 to 50	10 to 20		0 to 20
Loamy Fine Sand	0 to 25		50 to 90	10 to 20		0 to 20
Gravelly Sand Loam	25 to 50	25 to 50	0 to 50	20 to 50		0 to 20
Coarse Sand Loam	0 to 25	50 to 80		20 to 50		0 to 20
Sandy Loam	0 to 25	0 to 50	0 to 50	20 to 50		0 to 20
Fine Sandy Loam	0 to 25		50 to 80	20 to 50		0 to 20
Gravelly Loam	25 to 50			50 to 70	30 to 50	0 to 20
Loam	0 to 25	0 to 50	0 to 50	50 to 70	30 to 50	0 to 20
Silt Loam			0 to 50	50 to 100	50 to 100	0 to 20
GROUP 2:						
Gravelly Sand Clay Loam	25 to 80	0 to 80	0 to 80	20 to 50	0 to 30	20 to 30
Gravelly Clay Loam	25 to 50	0 to 50	0 to 50	50 to 80	20 to 50	20 to 30
Sandy Clay Loam	0 to 25	0 to 80	0 to 80	20 to 80	0 to 30	20 to 30
Clay Loam	0 to 25	0 to 50	0 to 50	50 to 80	20 to 50	20 to 30
Silty Clay Loam	0 to 25	0 to 30	0 to 30	70 to 100	50 to 80	20 to 30
GROUP 3:						
Sandy Clay	0 to 25	0 to 70	0 to 70	30 to 50	0 to 20	30 to 50
Clay			0 to 50	50 to 100	0 to 50	30 to 100
Silty Clay			0 to 20	80 to 100	50 to 70	30 to 50

Table A 5-692.603

5-692.604 SECONDARY CLASSIFIERS

A. SPECIAL TERMS FOR DESCRIBING SOIL

TOPSOIL - Any of the soil classes described above which contain large amounts of decomposed or partially decomposed organic matter. Top soils are distinguished by their dark brown to black color.

QUICKSAND - Defines a condition rather than a textural classification of soil. A “quick” condition may occur in gravel, sand, or silt because of an upward flow of water which “lifts” the particles and decreases stability.

GUMBO - A class of peculiar, fine-grained soil under poor drainage conditions. When saturated with water, gumbos are impervious and have a waxy or soapy appearance and feel.

DIATOMACEOUS EARTH - An accumulation of siliceous cell-walls of minute marine plants called diatoms. The soil in such deposits is fine-grained, is of uniform texture, and is very slippery when wet.

MARL - A general term applied to any earthy, crumbly deposit containing quantities of calcium carbonate, clay, fine sand, shell residues and carbonaceous material. It is very unstable when placed in water.

RESIDUAL SOILS - A term applied to soils that remain directly above the parent rock from which they have been derived by physical and chemical disintegration of that bedrock. Residual soils are more prevalent in older geological areas.

TRANSPORTED SOILS - Those which have been carried from their original position to their present location by the elements of nature, such as water, wind, gravity and moving ice.

TILL - Unstratified glacial drift soil, usually with stones and boulders intermingled. The term 'till' is normally applied to the lower stratum of soil layers or horizons which are only slightly or not at all weathered by the elements of nature such as freezing, thawing, percolating water, chemical changes, and plant organisms. A till soil thus remains very much in its parent state as deposited by glaciers. A sandy loam soil in the "C" horizon may be called "sandy loam till" (SLT) to describe it more completely if it is known to be of glacial origin.

HEAVY (TEXTURED) - Applied to soils of fine texture in which clay predominates, with dense structure and firm compact consistency. The term is also applied to soils containing a somewhat higher proportion of the finer particles than is typical of that textural class (as a "heavy sandy loam").

LIGHT (TEXTURED) - Applied to soils of coarse to medium texture, with very low silt and clay content, incoherent, single-grained structure, and loose consistency. The term is also applied to soils containing somewhat higher proportions of the coarser particles than is typical of that textural class (as a "light loam").

B. COLOR

In describing soils, color provides a first and quick means of identifying soil layers and the occurrence of similar soils in other localities. Color alone is not sufficient for identification, yet it can serve a useful purpose. To insure uniformity of description, soil colors are determined only when the soil contains moisture. Colors found in soils vary from tan, yellow or red to brown, dark gray or black. Color combinations are often used to make descriptions more complete, for example, a brownish-gray soil is a gray soil with a brownish cast.

MOTTLED: Presence of spots, streaks or splotches of one or more colors in a soil mass of another predominant color. In mottled soils the colors are not mixed and blended, but each is more or less distinct in the general ground color.

MARBLED: Presence of two or more distinct colors in approximately equal amounts but not blended. In a marbled soil there is no general or predominant color, as is the case of a mottled soil.

C. STRUCTURE

Structure describes the arrangement of individual soil grains into soil aggregations which make up the soil mass. It may refer to the natural arrangement of the soil when in place and undisturbed or to the soil at any degree of disturbance. The terms used below indicate the character of the arrangement and the general shape and size of aggregations.

CLODDY STRUCTURE: (Coarse, medium and fine). Aggregates of irregular shape, 37.5mm (1 1/2") to 200mm (8") in diameter, of firm consistency and more or less rounded in shape.

CRUMB STRUCTURE: (Coarse, medium and fine). Porous aggregates of irregular shape from more than 19mm (3/4") to less than 5mm (1/4") in diameter and of firm to soft consistency.

HARD PAN: A stratum of soil thoroughly cemented to an indurated, "rock-like" layer that will not soften when wet. The term "Hard Pan" is incorrectly applied to hard clay layers that are not cemented, or to those layers that may seem indurated, when dry, but which soften and lose their "rock-like" character when soaked in water. True hard pan is cemented by materials that are not readily soluble, and definitely and permanently (in nature) limits downward movement of roots and water.

CLAY PAN: A layer of stiff, compact, and relatively impervious clay. It is not cemented and can be worked into a soft mass when wet. Often called Gumbo, and many times erroneously called Hard Pan.

MASSIVE STRUCTURE: Single grained. Structureless. Showing no evidence of any distinct arrangement of soil particles.

LAMINATED STRUCTURE: An arrangement of the soil mass in very thin plates or layers, less than 1 millimeter (0.04”) in thickness, lying horizontal or parallel to the soil surface. Usually medium to soft consistency.

MEALY STRUCTURE: A crumb-like structure in which the aggregates are of soft to very soft consistency and usually less than 5mm (1/4”) in diameter.

FLUFFY STRUCTURE: A surface condition where the soil particles are loose, of light weight and fine texture, with no cohesion or evidence of arrangement; floury.

D. CONSISTENCY

The strength of cohesive soils is quantified by their consistency. Terms utilized to describe consistency are very soft, soft, firm (sometimes referred to as medium stiff), stiff, very stiff, and hard. Consistency is often thought of as relating to plasticity, since in clays short term strength is based on cohesion; however, it is possible to have a very plastic soil (high cohesion) appear very soft.

The following descriptive terms are offered to make this classification and identification a uniform system in the State of Minnesota: very soft, soft, firm, stiff, very stiff and hard.

E. COMPACTNESS

The strength of granular soils is quantified by their compactness. It is described as very loose, loose, medium dense (sometimes referred to as medium), dense, or very dense. Again, a sand with a high internal friction angle (indicative of high strength) may be encountered in a very loose condition, so associating strength, per se, with compactness is not necessarily correct.

The (SPT) Standard Penetration Test is widely used to evaluate the compactness of granular soils. This test is performed in accordance with ASTM D-1586.

In the case of silts, it is probably better to associate terms of consistency rather than compactness, since silts are difficult to compact and behave, under many circumstances, similarly to low-plasticity clays.

F. CEMENTATION

A condition occurring when the soil grains or aggregates are caused to adhere firmly and are bound together by some material that acts as a cementing agent (as colloidal clay, iron or aluminum hydrates, lime carbonate, etc.).

The degree of cementation when the soil is wetted should be stated. Some terms indicate the permanence as “indurated,” “hardpan,” etc.

Terms used to describe cementation are: Firmly cemented, indurated (rock-like), weakly cemented, softly cemented.

5-692.605 ORGANIC SOILS

Soils containing greater than 5 percent organic material by weight are defined as organic soils. Organic soils include plant material in various stages of decay from a condition where the stem and leaf structures can still be detected to a state where the plant tissue has lost its identity and an indefinite mass of organic material exists.

Organic soils can be classified as follows:

Classification	Organic Content by weight %
Non-organic	<2
slightly organic*	2 - 5
organic*	6 - 10
highly organic*	11 - 25
Peat-woody, fibrous, decomposed, etc.	>25

*Insert specific soil type, e.g. slightly organic, Silt Loam, Peaty loam, etc.

Muck is not a soil type and the term is often misused. The term "muck" is correctly used as in the construction item **Muck Excavation**. Mn/DOT 2105.2A3 reads:

Muck excavation shall consist of all saturated and unsaturated mixtures of soil and organic matter not suitable for foundation material regardless of moisture content, that is removed from below the natural ground level of marshes, swamps and bogs over which embankments are to be constructed, where the excavation is required:

(a) To provide a stable foundation for embankments, or
(b) To accelerate the subsidence of unstable material under embankment load.

5-692.606 AASHTO CLASSIFICATION

A. GENERAL

In 1928, the Bureau of Public Roads developed a system for classifying soils for highway engineering purposes based upon the observed performance of subgrade soils under highway pavements. The original system has been revised several times. Today the system is known as the AASHTO system of classification of Soils and Soil - Aggregate Mixtures for Highway Construction Purposes (AASHTO Designation M 145.)

The AASHTO system is an engineering property classification based upon field performance of subgrade soils under highway pavements. Subgrade soil materials are classified into seven major groups designated A-1 through A-7. The soils of each group have similar broad characteristics in common and physically react alike when subjected to loads. This system was developed so that a soil could be given a standard classification, no matter in what locality, county or part of the world it is found. This enabled engineers anywhere to talk the same language.

The AASHTO classification system has been adopted by the Minnesota Department of Transportation to correlate soils in Minnesota with standard classification procedures. The method is therefore included in its entirety in this manual. It is to be remembered that this classification system has been developed for engineering purposes and is not to be confused with the soil textural classification system described in the triangular chart, although the two are related.

B. SCOPE

Based upon their field performance, soils are classified by this procedure into seven groups which are designated as A-1, A-2, A-3, A-4, A-5, A-6, and A-7. The results of tests made in accordance with the methods hereinafter specified indicate the physical properties of the soils and serve to identify them with respect to grouping. Evaluation of soils within each group is made by means of a "group index" which is a value calculated by means of an empirical formula derived from observations of the behavior of soil and soil materials in embankments, subgrades, and subbases.

C. TEST PROCEDURES

The classification is based upon the results of tests made in accordance with the following standard methods of the AASHTO:

1. Amount of material finer than 75Φm (No. 200) Sieve in Aggreate T-11
2. Sieve Analysis of Fine and Coarse Aggregate.. T 27
3. Particle Size Analysis of Soils .... T 88
4. Liquid Limit of Soils.. T 89
5. Plastic Limit of Soils and Plastic Index .... T 90

D. GROUP INDEX CALCULATION

1. The group index is calculated from the following formula:
   Group index = (F-35) [0.2 + 0.005 (LL-40)] + 0.01 (F-15) (PI-10) in which,
   F = percentage passing 75Φm (No. 200)sieve, expressed as a whole number. This percentage is based only on the material passing the 75mm (3") sieve.
   LL = liquid limit
   PI = plasticity index
   a. When the calculated group index is negative, the group index shall be reported as zero (0).
   b. The group index should be reported to the nearest whole number.
2. Figure 1, AASHTO M 145, also, may be used in estimating the group index, by determining the partial group index due to liquid limit and that due to plasticity index, then obtaining the total of the two partial group indexes.

3. When calculating the group index of A-2-6 and A-2-7 subgroups, only the PI portion of the formula shall be used.
4. The following are examples of calculations of the group index:
   a. Assume that an A-6 material has 55 percent passing the 75Φm (No. 200) sieve, liquid limit of 40, and plasticity index of 25. Then, Group index = (55-35)[0.2 + 0.005 (40-40)] + 0.01 (55-15) (25-10) = 4.0 + 6.0 = 10
   b. Assume that an A-7 material has 80 percent passing the 75Φm (No. 200) sieve, liquid limit of 90, and plasticity index of 50. Then, Group index = (80-35)[0.2 + 0.005(90-40)] + 0.01 (80-15) (50-10) =20.3 + 26.0 = 46.3
   c. Assume that an A-4 material has 60 percent passing the 75Φm (No. 200) sieve, liquid limit of 25, and plasticity index of 1. Then, Group index = (60-35)[0.2 + 0.005 (25-40)] + 0.02 (60-15) (1-10)= 25 X (0.2 - 0.075) + 0.01(45)(-9) = 3.1 - 4.1 = -1.0
      Report as 0.
   d. Assume that an A-2-7 material has 30 percent passing the 75Φm (No. 200) sieve, liquid limit of 50, and plasticity index of 30. Then, Group index = 0.01(30-15) (30-10) = 3.0 or 3 (Note that only the PI portion of formula was used.)

E. BASIS FOR GROUP INDEX FORMULA

1. The empirical group index formula devised for within-group evaluation of the “clayey granular materials” and the “silt-clay materials” is based on the following assumptions:
   a. Materials falling within Groups A-1-a, A-1-b, A-2-4, A-2-5, and A-3 are satisfactory as subgrade materials when properly drained and compacted or can be made satisfactory by addition of small amounts of natural artificial binders.
   b. Materials falling within the “clayey granular” Groups A-2-6 and A-2-7 and the “silt-clay” Groups A-4, A-5, A-6, and A-7 will range in quality as subgrade from the approximate equivalent of good A-2-4 and A-2-5 subgrades to fair and poor subgrades requiring a layer of subbase material or an increased thickness of base coarse over that: required under a., in order to furnish the adequate support for traffic loads.
   c. The assumed critical minimum percentage passing the 75Φm (No. 200) sieve is 35 neglecting plasticity, and 15 as affected by plasticity indexes greater than 10.
   d. Liquid limits of 40 and above are assumed to be critical.
   e. Plasticity indexes of 10 and above are assumed to be critical.
   f. For soils that are non-plastic and when the liquid limit cannot be determined, the group index shall be considered zero (0).
2. There is no upper limit of group index value obtained by use of the formula. The adopted critical values of percentage passing the 75Φm (No. 200) sieve, liquid limit and plasticity index, are based on an evaluation of subgrade, subbase and base course materials by several highway organizations that use the tests involved in this classification system.

3. Under average conditions of good drainage and thorough compaction, the supporting value of a material as subgrade may be assumed as an inverse ratio to its group index; that is, a group index of 0 indicates a "good" subgrade material and group index of 20 or greater indicates a "very poor" subgrade material.

F. CLASSIFICATION

1. General
   The classification is made by using the test limits and group index values shown in Table A 5-692.606.

   Classification Procedure. - With required test data available, proceed from left to right in Table A 5-692.606, and the correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification. All limiting test values are shown as whole numbers. If fractional numbers appear on test reports, convert to nearest whole number for purposes of classification. Group index values should always be shown in parentheses after group symbol as A-2-6 (3), A-4 (5), A-6 (12), A-7-5 (17), etc.
2. Definition of Gravel, Sand and Silt-Clay
   The terms "gravel", "coarse sand", "fine sand", and "silt-clay", as determined from the minimum test data required in this classification arrangement and as used in subsequent word description, are defined as follows:
   a. Gravel - Material passing sieve with 75mm (3") square openings and retained on the 2mm (No. 10) sieve.
   b. Coarse Sand - Material passing the 2mm (No. 10) sieve and retained on the 425Φm (No. 40) sieve.
   c. Fine Sand - Material passing the 425Φm (No. 40) sieve and retained on the 75Φm (No. 200) sieve.
   d. Combined Silt and Clay - Material passing the 75Φm (No. 200) sieve.
   e. Boulders (retained on 75mm (3") sieve) should be excluded from the portion of the sample to which the classification is applied, but the percentage of such material, if any, in the sample should be recorded.
   f. The term "silty" is applied to fine material having plasticity index of 10 or less and the term "clayey" applied to fine material having plasticity index of 11 or greater.
3. AASHTO Classification System (formerly, Highway Research Board Classification)
   This classification system divides soils into two major groups. One group which includes the A-1, A-2 and A-3 classes is composed of soils that have 35% or less passing a 75Φm (No. 200) sieve. The second group, A-4, A-5, A-6, A-7, is composed of soils that have more than 35% passing a 75Φm (No. 200) sieve.

The two major groups in the soil classification are further divided into additional groups and subgroups as follows:

a. Granular materials:

Group A-1 - Well-graded mixtures of stone fragments of gravel ranging from coarse to fine with a non-plastic or slightly plastic soil binder. However, this group also includes coarse materials without soil binder.
Subgroup A-1-a - Materials consisting predominantly of stone fragments or gravel, either with or without a well-graded soil binder of fine materials.
Subgroup A-1-b - Materials consisting predominantly of coarse sand either with or without a well-graded soil binder.

Group A-3 - Materials consisting of sands deficient in coarse material and soil binder. Typical is fine beach sand or fine desert blow sand, without silt or clay fines or with a very small amount of non-plastic silt. This group also includes stream-deposited mixtures of poorly graded fine sand and a limited amount of coarse sand and gravel. These soils make suitable subgrades for all types of pavements when confined and damp. They are subject to erosion and have been known to pump and blow under rigid pavements. They can be compacted by vibratory, pneumatic-tired, and steel-wheel rollers but not with a sheepsfoot roller.

Group A-2 - This group includes a wide variety of "granular" materials which are borderline between the materials falling in Groups A-1 and A-3 and the silt clay materials of Groups A-4, A-5, A-6, and A-7. It includes all materials containing 35 percent or less passing the 75Φm (No. 200) sieve which cannot be classified as A-1 or A-3.

Subgroups A-2-4 and A-2-5 include various granular materials containing 35 percent or less passing the 75Φm (No. 200) sieve and with a minus 425Φm (No. 40) portion having the characteristics of the A-4 and A-5 groups. These groups include such materials as gravel and coarse sand with silt contents or plasticity indexes in excess of the limitations of Group A-1, and fine sand with non-plastic silt content in excess of the limitations of Group A-3. Subgroups A-2-6 and A-2-7 include materials similar to those described under Subgroups A-2-4 and A-2-5, except that the fine portion contains plastic clay having the characteristics of the A-6 or A-7 group. The approximate combined effects of plasticity indexes in excess of 10 and percentages passing the 75Φm (No. 200) sieve in excess of 15 is reflected by group index values of 0 to 4.

A-2 soils are given a poorer rating than A-1 soils because of inferior binder, poor grading, or a combination of the two. Depending on the character and amount of binder, A-2 soils may become soft during wet weather and loose and dusty in dry weather when used as a road surface.

If, however, they are protected from these extreme changes in moisture content, they may be quite stable. The A-2-4 and A-2-5 soils are satisfactory as base materials when properly compacted and drained, while A-2-6 and A-2-7 soils may lose stability because of capillary saturation or lack of drainage. A-2-6 and A-2-7 soils with low percentages of minus 75Φm (No. 200) material are classified as good bases, whereas these same soils with high percentages of minus 75Φm (No. 200) and P.I.'s of 10 or higher are questionable as a base material. Frequently the A-2 soils are employed as a cover material for very plastic subgrades.

b. Silt-Clay Materials:

Groups A-4 - The typical material of this group is a non-plastic or moderately plastic silty soil usually having 35 percent or more passing the 75Φm (No. 200) sieve. The group incudes also mixtures of fine silty soil and up to 64 percent of sand and gravel retained on the 75Φm (No. 200) sieve. The group index values range from 1 to 8, with increasing percentages of coarse material being reflected by decreasing group index values. These predominantly silty soils are quite common in occurrence. Their texture varies from sandy loams to silty and clayey loams. With the proper amount of moisture present, they may perform well as a pavement component. However, they frequently have an affinity for water and will swell and lose much of their stability unless properly compacted and drained. Moreover, they are subject to frost heave. Since these soils do not drain readily and may absorb water by capillarity with resulting loss in strength, the pavement structural design section should be based on the strength of the soils when saturated. The silty loams are often difficult to compact properly. Careful field control of moisture content and pneumatic-tired rollers are normally required for proper compaction.

Group A-5 - The typical material of this group is similar to that described under Group A-4, except that it is usually of diatomaceous or micaceous character and may be highly elastic as indicated by the high liquid limit. The group index values range from 1 to 12, with increasing values indicating the combined effect of increasing liquid limits and decreasing percentages of coarse material. These soils do not occur as widely as the A-4 soils. They are normally elastic or resilient in both the damp and semi-dry conditions. They are subject to frost heave, erosion, and loss of stability if not properly drained. Since these soils do not drain readily and may absorb water by capillarity with resulting loss in strength, the pavement structural design section should be based on the strength of the soils when saturated. Careful control of moisture content is normally required for proper compaction.

Group A-6 - The typical material of this group is a plastic clay soil usually having 35 percent or more passing the 75Φm (No. 200) sieve. The group includes also mixtures of fine clayey soil and up to 64 percent of sand and gravel retained on the 75Φm (No. 200) sieve. Materials of this group usually have high volume change between wet and dry states. The group index values range from 1 to 16, with increasing values indicating the combined effect of increasing plasticity indexes and decreasing percentages of coarse material. These soils are quite common in occurrence and are widely used in fills. When moisture content is properly controlled, they compact quite readily with either a sheepsfoot or pneumatic-tired roller. They have high dry strength but lose much of this strength upon absorbing water. The A-6 soils will compress when wet and shrink and swell with changes in moisture content. When placed in the shoulders adjacent to the pavement, they tend to shrink away from the pavement edge upon drying and thereby provide an access route to the underside of the pavement for surface water. The A-6 soils do not drain readily and may absorb water by capillarity with resulting loss in strength. Therefore, the pavement structure design section should be based on the strength of the soils when saturated.

Group A-7 - The typical materials and problems of this group are similar to those described under Group A-6, except that they have the high liquid limits characteristic of the A-5 group and may be elastic as well as subject to high volume change. The range of group index values is 1 to 20 with increasing values indicating the combined effect of increasing liquid limits and plasticity indexes and decreasing percentages of coarse material.

Subgroup A-7-5 includes those materials with moderate plasticity indexes in relation to liquid limit and which may be highly elastic as well as subject to considerable volume change.

Subgroup A-7-6 - includes those materials with high plasticity indexes in relation to liquid limit and which are subject to extremely high volume change.

Highly organic soils may be classified in an A-8 group. Classification of these materials is based on visual inspection, and is not dependent on percentage passing the 75Φm (No. 200) sieve, liquid limit or plasticity index. The material is composed primarily of partially decayed organic matter, generally has a fibrous texture, dark brown or black color and odor of decay.

These organic materials are unsuitable for use in embankments and subgrades. They are highly compressible and have low strength.

TABLE A
CLASSIFICATION OF SOILS AND SOIL-AGGREGATE MIXTURES

General Classification	Granular Materials (35% or less passing 75µm) [No. 200]							Silt-Clay Materials (More than 35% passing 75µm) [No. 200]			
Group Classification	A-1		A-3*	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis:											
Percent passing:											
2mm (No. 10)	50 max.	---	---	---	---		---	---	---	---	---
425µm (No. 40)	30 max.	50 max.	51 min.	---	---	---	---	---	---	---	---
75µm (No. 200)	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 425µm (No. 40):											
Liquid Limit	---		---	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity Index	6 max.		N.P.	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min**
Usual Types of Significant Constituent Materials	Stone Fragments Gravel and Sand		Fine Sand	Silty or Clayey Gravel and Sand				Silty Soils		Clayey Soils	
General Rating as Subgrade	Excellent to Good							Fair to Poor			

The placing of A-3 before A-2 is necessary in the "left to right elimination process" and does not indicate superiority of A-3 over A-2.
**Plasticity Index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity Index of A-7-6 subgroup is greater than LL minus 30.

5-692.607 SOIL SELECTION GUIDE FOR FIELD INSPECTORS

A. General

One of the most important functions of the grading inspector is the selection of soils for placement in the road structure. The embankment soils are the foundation materials that will ultimately support the loads imposed on the finished road structure and the soils selected for placement in the upper portion of the grade should be the best available. This section of the Manual is designed to assist the inspector to evaluate the soils on his project and to select the best soils for embankment construction.

In order to intelligently select soils for placement in the grade, it is necessary to understand what engineering properties are desirable and to be able to identify, in the field, soils having those properties.

Soils are composed of four components, gravel, sand, silt and clay. All soils are made up of one or more of these components in varying combination. The influence of each of these components affects the performance of a foundation soil. Gravel is relatively frost free and is not as susceptible to moisture changes as silt, sand or clay. Sand, if it is sharp edged and angular, helps prevent slippage in the soil mass, is not susceptible to frost or minor moisture changes and contributes to the stability of the embankment. Silt is highly susceptible to moisture changes, has a fairly large volume change between the wet and dry states and when silt is the predominant component, the soil is unstable if exposed to moisture. In small quantities, silt fills voids and helps to provide a well-graded, dense soil mass. Clay includes a wide range of materials from highly stable to unstable soils. In the proper proportion, it provides cohesion and helps to cement the soil mass together and increase the stability. A well graded soil combining all of the above components in the proper proportions will provide a dense, highly stable embankment.

Most of the tests made to measure the engineering properties of soils cannot be made in the field. These tests include the determination of the silt and clay fractions, the liquid limit and plastic limit tests and the computations to determine the AASHTO group classification. Although, these tests can not be made in the field, they have been made for samples submitted to the laboratory by the Soils Engineer during his soil survey and copies of these tests should be obtained from him and used by the inspector to compare with his field identifications to help control the work. The tests are also routinely made on all samples submitted to the laboratory during construction.

The test results of laboratory samples are reduced to 3 significant terms:

1. Textural Classification
2. AASHTO classification system which classifies soils into 7 groups designated A-1 through A-7.
3. Group Index which is a numerical rating that can range from 0 to 20 or more with the best soils having a value of 0 and the poorest having values of 20 or greater.

The textural classification can be determined in the field by visual inspection and by “feel”. Comparison of like textural classifications can provide an estimate of the AASHTO group classification. With practice, considerable proficiency can be attained.

B. Soil Identification

If the information furnished by the AASHTO Classification System is to be used effectively by the Inspector, it is necessary to provide a quick, simple method of identifying soils in the field having the same characteristics as those tested in the laboratory. The laboratory report identifies the sample by “Textural Class”. The textural class is determined from the proportions of sand, silt and clay in the sample by means of the triangular chart. The textural classification of soils can be determined in the field by “feel” and visual inspection. By comparison with the laboratory samples, an estimate of the AASHTO group classification can be obtained and the textural classification can be used as a guide in selecting embankment soils. The field method for determining the textural classification involves determining the effect of sand grains by “feel” and the effect of plastic soils by forming a cast in the hand and by pressing or rubbing a moist sample between the thumb and forefinger to form a thin ribbon until it will break under its own weight when held in a horizontal position.

SOIL IDENTIFICATION					
TEXTURAL CLASS	**IDENTIFICATION BY FEEL**	**RIBBON LENGTH**	**AASHTO GROUP (H.R.B. CLASS)**	**GROUP INDEX**	**RATING FOR UPPER EMB.**
Gravel (G)	Stones: Pass 75mm (3”) sieve, Retained on 2mm (No. 10)	0	A-1-a	0	Excellent
Fine Gravel (FG)	Stones: Pass 9.5mm (3/8”) sieve, Retained on 2mm (No. 10)	0	A-1-a	0	Excellent
Sand (S)	100% pass 2mm (No. 10). Less than 10% silt and clay	0	A-1-b	0	Excellent
Coarse Sand (CrS)	Pass 2mm (No. 10), Ret. 425µm (No. 40).	0	A-1-a or A-1-b	0	Excellent
Fine Sand (FS)	Most will pass 425µm (No. 40), Gritty, non-plastic	0	A-1-b or A-3	0	Excellent to Good
Loamy Sand (LS)	Grains can be felt. Forms a cast.	0	A-2-4 or A-2-5	0	Excellent to Good
Sandy Loam (SL) a. sightly plastic (slpl)	0-10% clay. Gritty.	0 - 19mm (0-3/4”)	A-2-4, A-2-6 or A-2-7	0 - 4	Excellent to Good
b. plastic (pl)	10-20% clay. Gritty.	19mm (0-3/4”) - 37.5mm (1 1/2”)	A-4	1 - 13	Excellent to Good
Loam (L)	Gritty, but smoother than SL.	5mm (1/4”) - 37.5mm (1 1/2”)	A-4	1 - 13	Excellent to Good
Silt Loam (SiL) a. sightly plastic (slpl)	0-10% clay. Smooth, slippery or velvety. Little Resistance	0 - 19mm (3/4”)	A-4	0-13	Fair to Poor
b. plastic (pl)	10-20% clay. Smooth, slippery or velvety. Little Resistance .	19mm (0-3/4”) - 37.5mm (1 1/2”)	A-4	1 - 13	Fair to Poor
Silt (Si)	>80% Silt. Small, slippery or velvety. Little Resitance.	0 - 15mm (0-1/2”)	A-4	1 - 13	Poor
Clay Loam (CL)	Smooth, shiny, considerable resistance.	37.5mm (1 1/2”) - 62..5mm (2 1/2”)	A-6	1 - 40	Good to Fair
Silty Clay Loam (SiCL)	Dull appearance, slippery, less resistance.	37.5mm (1 1/2”) - 62..5mm (2 1/2”)	A-6 or A-5	1 - 40	Fair to Poor
Sandy Clay Loam(SCL)	Somewhat gritty. Considerable resistance.	37.5mm (1 1/2”) - 62..5mm (2 1/2”)	A-6 or A-5	1 - 40	Good to Fair
Clay (C)	Smooth, shiny, long thin ribbon.	> 62..5mm (2 1/2”)	A-7	1 - 40	Fair to Poor
Silty Clay (SiC)	Buttery, smooth, slippery.	> 62..5mm (2 1/2”)	A-7 or A-7-5	1 - 40	Poor
Sandy Clay (SC)	Very plastic but gritty. Long, thin ribbon.	> 62..5mm (2 1/2”)	A-7 or A-7-6	1 - 40	Fair to Poor

Where the group index is expressed as a range, such as 0-40, the lower values are the better foundation soils.

Table A 5-692.607

1. Gravel (G)
A combination of stones that will pass a 75mm (3”) sieve and be retained on a 2mm (3/8”) sieve. Fine Gravel (FG) has a predominance of stones between the 9.5mm (No. 10) and 2mm (No. 10) sieves. These materials can be classified by visual inspection. The AASHTO classification is A-1-b and the Group Index is 0.

2. Sand (S)
100% of this material will pass a 2mm (No. 10) sieve and will have less than 10% silt and clay combined. It will not form a ribbon. It will generally fall in the A-1-b group with a Group Index of 0.

   Coarse Sand (CrS). The predominant size is material that will pass a 2mm (No. 10) sieve and be retained on a 425Φm (No. 40) sieve. It will not form a ribbon. AASHTO classification, A-1-a. Group Index 0.

   Fine Sand (FS) the predominant size is material that will pass the 425Φm (No. 40) sieve and be retained on a 75Φm (No. 200) sieve. It will not form a ribbon. AASHTO classification, A-1-b or A-3, Group Index, 0.

3. Loamy Sand (LS)
100% of this material will pass a 2mm (No. 10) sieve and will contain between 10 and 20% of the fine grained silt and clay. This material is loose and granular when dry and the individual grains can be seen and felt. When moist, it will form a cast, but because it is non-plastic, it cannot be pressed into a ribbon. Loamy sand can be further classified as Loamy Coarse Sand (LCrS). Loamy Fine Sand (LFS) or Loamy Very Fine Sand (LVFS). These soils will be generally classified as A-2-4 or A-2-5, but may be classified as A-3 or A-1-b. Group Index, 0.

4. Sandy Loam (SL)
This soil contains 20% to 50% silt and clay combined, but less than 20% clay. It must always contain 50% or more sand grains to be classified as sandy loam. Sandy loam is divided into two main groups, slightly plastic and plastic sandy loam.

   Slightly Plastic Sandy Loam (sl pl SL) generally contains 10% or less clay. It will form a thin ribbon 0-19mm (0-3/4”) in length before breaking under its own weight. AASHTO classification, A-2-4, A-2-6 or A-2-7, Group Index 0 to 4.

   Plastic Sandy Loam (pl SL) contains about 10% to 20% clay. It will feel gritty and can be pressed into a ribbon form 19mm (0-3/4”) to 25mm (1”) in length. Generally, the approximate group index value(s) for AASHTO classifications for A-2-4 and A-2-5 is 0 and for A-2-6 and A-2-7, the values range from 1-13.

5. Loam (L)
Loam always contains more than 50% silt and clay combined. It is a relatively even mixture of sand and silt with less than 20% clay. It has a somewhat gritty feel but is smoother than a sandy loam. It will form a ribbon 5mm (1/4”) to 37.5mm (1 1/2”) in length, but will be thinner and stronger than can be formed with sandy loam. AASHTO classification A-4. The Group Index values range from 1 to 13.

6. Silt Loam (SiL) and Silt (Si)
   Silt Loam contains more than 50% silt, 0 to 50% sand and less than 20% clay. (If the soil contains more than 80% silt and 0 to 20% sand, it is classified as a silt.) When pressed between the fingers, it will offer little resistance to pressure and feels smooth, slippery or "velvety". Silt Loam is classified as slightly plastic when the ribbon length is between 0 and 19 mm (0 and 3/4") and is classified as plastic Silt Loam when the ribbon length is between 19mm (3/4") and 37.5mm (1 1/2") Pure silt is non-plastic and will not press into a continuous ribbon, but it will press into ribbons of up to 0 -10mm (0-1/2") in length, depending on the clay content AASHTO Classification, A-4, Group Index, 0 to 13.

7. Clay Loam (CL)
   Clay loam contains 20% to 30% clay, 20% to 50% silt and 20% to 50% sand. It is fine textured and will form a ribbon from 37.5mm (1 1/2") to 62.5mm (2 1/2") in length before breaking. It requires considerable pressure to form a ribbon. AASHTO classification, A-6, Group Index, 1 to 40.

8. Silty Clay Loam (SiCL)
   Silty Clay Loam contains 20% to 30% clay, 50% to 80% silt and 0 to 30% sand. This is a fine textured soil and will form a ribbon 37.5mm (1 1/2") to 62.5mm (2 1/2") in length without breaking. It does not offer as much resistance to pressure as clay loam and has a dull appearance, but is slippery. AASHTO classification A-6, but may be an A-5, if elastic, Group Index, 1 to 40.

9. Sandy Clay Loam (SCL)
   Sandy Clay Loam contains 20% to 30% clay, 50% to 80% sand and 0 to 30% silt. It has a gritty feel compared to the more slippery feel of clay loam. It will form a ribbon 37.5mm (1 1/2") to 62.5mm (2 1/2") in length. AASHTO classification, A-6 Group Index, 1 to 40.

10. Clay (C)
    Clay contains from 30% to 100% clay, 0 to 50% silt and 0 to 50% sand. It is smooth and shiny and will form a long, thin, flexible ribbon 62.5mm (2 1/2") or more in length. AASHTO classification A-7. Group Index, 1 to 40.

11. Silty Clay(SiC)
    Silty Clay contains 30% to 50% clay 50% to 70% silt and 0 to 20% sand. It is very plastic but feels smooth and slippery and will form a ribbon 62.5mm (2 1/2") or more in length. It is buttery. AASHTO classification, A-7 or A-7-5, Group Index, 1 to 40.

12. Sandy Clay (SC)
    Sandy Clay contains 30% to 50% clay, 50% to 70% sand and 0 to 20% silt. It is very plastic, but feels gritty. It will form a long, thin ribbon 62.5mm (2 1/2") or more in length. AASHTO classification A-7 or A-7-6. Group Index, 1 to 40.

The group index values shown for: Soils No.'s 4, 5 and 6 decrease with increasing percentages of coarse material. Soils No.'s 7, 8 and 9 increase with increasing percentage of coarse material. Soils No.'s 10, 11 and 12 increase due to the combined affect of increasing liquid limits and plasticity indexes and decreasing percentaages of coarse material.

See Tab. A 5-692.607 for a summary of the above.

5-692.620 SOIL PROFILE

5-692.621 DEFINITION (Soil Profile)

"Soil profile" is the term applied to a vertical section from the ground surface down through the weathered soil horizons and into the underlying, parent material. This term was originally used by soil surveyors in the method developed by them for mapping soils for agricultural purposes. It has since been adapted to use quite commonly by engineers in making soil surveys for engineering purposes.

The term "soil horizon" refers to a soil condition formed by the process of weathering and should not be confused with differing soil types, which commonly form in layers as a result of glacial deposition. By the following definitions, there are only four (A through D) soil horizons possible, while any number of soil types or layers may be present in a highway cut.

5-692.622 DEVELOPMENT OF SOIL PROFILE

The soil profile is composed of a series of distinct soil layers, or horizons as they are called. These horizons are the result of weathering action of the elements through centuries of time upon the parent material or original unweathered geological formation. This parent material when first deposited by glaciers, by wind, or by water was the same at the surface as down within the deposit; that is, there were no horizons of weathered soil at the surface. These horizons developed later through the action of water, wind, sun, freezing and thawing and bacteriological life which evolved with growing and dying vegetation.

Gradually, in humid regions, these processes resulted in leaching out some of the water soluble materials in the uppermost or top zone. Percolating water carried with it the soluble matter together with the fine soil material in suspension as it seeped downward. As the rate of downward flow slowed with depth, the soluble material and soil in suspension were deposited at a lower level, resulting in a zone of accumulation. As a consequence, the top soil horizon became lighter in texture as some of the finer clay particles were carried out of it. The second zone then became heavier textured due to the clay and other substances added to it. In standard soil terminology, these soil horizons are designated as:

"A" HORIZON

This is the surface or top zone of soil. It is generally “lighter” textured, sandier, and more friable than the underlying horizons. It is usually distinguished by a darker color than the lower horizons because of the accumulation of decomposed organic matter. As a result of this high organic content, “A” horizon soil exhibits undesirable and unsatisfactory engineering characteristics, such as high compressibility and elasticity, and unfavorable resistance to compaction.

"B" HORIZON

The second soil zone below the surface is known as the “B” horizon. It is sometimes referred to as the zone of accumulation due to the collection of material leached out of the “A” horizon. The “B” horizon is fairly uniform in color and of a lighter color than the “A” horizon. It generally varies from about 0.5m (1 1/2’) to 1m (3’)in thickness. “B” horizon soil is normally heavier textured than the “A” horizon but is uniform and evenly textured. For this reason, it is often the most desirable material for highway construction.

"C" HORIZON

The "C" horizon is the stratum below the "B" horizon and is the third zone below the surface. "C" horizon material remains in the same physical and chemical state as when it was first deposited. It is the unweathered, parent material. It is generally lighter in color than both the "A" and "B" horizons and thus readily distinguished from the overlying zone. It may be of indefinite thickness, extending below the elevation of interest to the highway engineer even in the deep cuts. It is entirely possible that the "C" will be composed of several soil types or layers. If the overlying soil is inplace weathered bedrock (residuum) then the “C” horizon will be parent bedrock.

"D" HORIZON

The stratum of material underlying the "C" horizon is known in geology as the "D" horizon. The "D" horizon is ordinarily embedded rock which is not the soils parent material and not generally of importance in soils engineering. Only a few meters or as much as a few hundred meters may separate the "A" and "B" horizons from the bedrock.

5-692.623 PRAIRIE SOILS

In prairie regions, the "A" horizon acquires its dark color because of the accumulation of organic matter. The growth of vegetation goes on in cycles; it grows, dies, and decomposes. The decomposed or partly decomposed carbonaceous matter thus produced imparts the dark coloring to the soil, ranging from gray to dark brown to black. Intensity of coloring and its depth depend upon the kind of vegetation, climate, topography, and other factors. In Minnesota, the "A" horizon may be less than 100mm (4”) thick on the tops of knolls in hilly country where erosion removes it about as fast as it develops. In low-lying poorly-drained areas, it may be as thick as 1 to 2 meters (3 to 6 feet) and more where vegetation grows abundantly and additional material may be washed in and deposited. The "B" horizon is frequently more uniform in thickness within a given area, since it is not affected as much by erosion.

5-692.624 FOREST SOILS

In forested country, where forest conditions have prevailed, the "A" horizon is usually light gray in color, sometimes becoming almost a white or ashy color when dry. The soil is also typically light-textured and usually cohesionless. A layer of leaf mold may often occur as a thin cover only 25 to 50 mm (1-2 inches) thick over the mineral soil. The "B" horizon soil is frequently quite heavy and plastic. Forest soils having these characteristics are called "Podsols" when the light colored "A" horizon is strongly developed. When not so strongly developed, they are said to be "podsolized."

5-692.625 TYPES OF SURFICIAL GEOLOGIC DEPOSITS IN MINNESOTA

The general terrain through or on which any transportation project will be located will be composed of one or more individual land forms. The soil materials in each of these land forms is related to the mode of deposition and subsequent weathering or reworking. Recognition of typical Minnesota land forms will provide an insight into the general type of soil to be encountered and thus the anticipated degree of uniformity and engineering characteristics.

Almost all of the topography in Minnesota is related to the Wisconsin glacial period, which is the name given to the last of six major ice advances into the State (Figure 1 5-692.625). The last ice remnants of this glacial period retreated from the State 10,000-12,000 years ago. Soils deposited or formed since that time are referred to as being of recent or modern origin. Most Minnesota soils are related in some way to a glacial period, but some recent river or swamp deposits exist, as do residual soils which have weathered inplace on top of the bedrock surface. It is frequently difficult to distinguish some recent soils from similar older glacial soils.

Soils in Minnesota can be associated with one of five categories of surficial geologic deposits: glacial drift, windblown deposits, recent deposits, gravity deposits and residual soils.

A. GLACIAL DRIFT

All soil materials derived from or directly related to glacial activity can be collectively referred to as drift. This would include such diverse soils as glacial lake clays, outwash sands and gravels, clay loams, sandy loam till, etc. Drift thickness are as great as 150 meters (500 feet) in parts of northwestern and central Minnesota.

Wisconsin glacialion is characterized by several advances of four major ice lobes protruding from the main ice sheet in Canada into Minnesota. These four lobes, distinguished by their flow direction are the Wadena Lobe, Rainy Lobe, Superior Lobe and Des Moines Lobes. The Wisconsin glacialion is summarized in Figure 1 5-692.625

The Rainy and Superior lobes advancing from the northeast (Patrician and Labradorean ice centers) entered the state through the Iron Range and Arrowhead Regions, overriding reddish colored sandstone, iron formations, and igneous and metamorphic bedrock. Rock picked up by this ice is therefore very hard usually reddish or gray-black in color and the soils deposited have a reddish to reddish-brown cast and are generally sandy in texture. Soils of northeastern origin, frequently called “red drift,” cover northeastern Minnesota north of the Twin Cities area and generally west to the Mississippi River. These soils generally have a soil texture of sandy loam.

The Wadena and Des Moines lobes advanced into Minnesota from the north and northwest and deposits formed by this ice are frequently called “gray drift.” Soils associated with this drift were derived from sedimentary rock such as limestone and shale, therefore rocks included in this drift are comparatively soft and have a grayish to brown color. These soils typically contain a high percentage of shale and limestone particles. Generally, soil textures consist of plastic loam, clay loam and clay, with a brown to yellowish-brown color near the surface where the iron in the soil has been oxidized or rusted. Such soils cover most of western and southern Minnesota.

It should be mentioned that not all deposits are distinctly reddish or gray colored, but may be complex mixtures of these types with a thin layer of one overlying the other where ice sheets have met. “Red and gray drift” soils have distinctive engineering characteristics, with the “Red drift” types being considerably more moisture sensitive and difficult to work at moisture contents above optimum.

Drift which has not been reworked or sorted in any manner (unstratified) will include a wide range of particle sizes (from boulders to clay) and is referred to as till. Thus, clay loams or sandy loams with pebbles and stones, known to be glacial origin may be termed clay loam till or sandy loam till. On the other hand, glacial soils reworked by water or wind are technically called stratified drift and this general classification would include the most common soil types such as clay, sand, clay loam, etc.

B. GLACIAL LANDFORM DESCRIPTIONS

Some of the more common types of glacial land forms are described below:

1. Moraines-Deposits of unstratified glacial till dropped directly from the margins of the ice sheet as the ice melts in a relatively stagnant position. Wide ranges of soil types should be expected, but the most common types would be clay loam till, sandy loam till, etc. Sand, gravel and silt are frequently found interspersed with the more plastic soils and abrupt lateral textural changes can be expected. Drainage of such soil types is slow and water volumes are usually not great. Terminal and recessional moraines mark the farthest advance of an ice sheet or an intermediate stopping point in its retreat. In an ice sheet that maintains a relatively stagnant position, the rate of ice melting roughly equals the rate of ice advance and thus rather large quantities of soil carried by the ice are liberated. Such deposits are usually characterized by relatively high, rugged topography and lakes are common. Ground moraines or till plain are rolling to relatively flat features and form as the ice retreats uniformly or melts in a stagnant position.
2. Drumlins - When an ice sheet moves over previously formed ground moraine, the older moraine may be remodeled into elongate “cigar shaped” ridges called drumlins, with the long axes paralleling the direction of ice movement. A group of drumlins may frequently be found clustered together in one area. Soil types will be the same as the parent moraine.
3. Outwash - As the ice melted, streams carrying large sediment loads fanned out from the face of the ice sheet. As stream velocity decreased and coarser particles were dropped out, rather level to gently undulating outwash plains of stratified sand, gravel and sometimes silt, were deposited. A pitted outwash plain is formed when blocks of ice break off the main glacier, are buried and then later melt, forming depressions or kettles in the outwash. (Kettles may also form similarly in moraines.)

Valley trains are outwashes confined to old drainage valleys. Outwash features will be primarily granular, with changes in texture taking place rather gradually both horizontally and vertically. Such features may cover broad areas or be confined to narrow bands, but in either form they are usually good sources of sand, gravel and water. Grades below the water table will be difficult to dewater because of the quantity of water present and the ease of recharge. Outwash deposits frequently rest on top of older till and are associated in origin with adjoining moraines. (Outwash and ice contact deposits that are formed by streams associated with glaciers are termed glaciofluvial.)

4. Ice Contact Deposits
   The following three types of deposits: kames, eskers, and collapse sediments, are frequently referred to by the general term ice contact deposit, that is, they form on, within or immediately adjacent to the ice sheet. Such features are usually granular, but can be distinguished from typical outwash by the following characteristics: 1) extreme range and abrupt changes in grain size, 2) included bodies or zones of till, 3) marked deformation of bedding features and 4) usually of rather limited extent.
   a. Kames - These are knob-like to irregular shaped isolated hills rising above the general terrain. Soils within the kame are crudely stratified gravel, sand and silt. Coarser sediments are typically located toward the center of the kame. Kames form where sediments are deposited by running water at the edge of an ice mass, in crevasses or in other openings on or in a stagnant or nearly stagnant ice mass. When the ice later melts away, the accumulated sediment remains in the form of isolated mounds. Kames and kettles are often found in close association.
   b. Eskers - One of the better known glacial topographic forms is the esker, which is a long, narrow, sinuous ridge, composed mostly of sand and gravel. Like all ice contact deposits, particle sizes range from boulders to very fine sand are common. Esker deposits may have formed in surface channels on the ice, but more likely they originate from filling of long crevasses or channels within or beneath the ice sheet. These old channels were frequently eroded below the level of the surrounding till and thus granular soils may likewise extend to some depth. Steeply inclined stratification on the flanks is not uncommon.
   c. Collapse Sediments - These are basically stratified granular soils deposited on the surface of the ice flow by streams and let down onto the ground surface as the stagnant ice melted.

5. Glacial Lakes - In front of the ice flow, lakes formed in surface depressions and these stagnant water bodies provided settling points for silts and clays. (Sediments deposited in lakes fed by glacial melt water streams are termed glaciolacustrine.) Some of these lakes covered many square miles, with the largest and best known being Glacial Lake Agassiz, which covered a large part of northwestern Minnesota. Most of these lake clays are troublesome to the engineer because of their poor drainage characteristics, low strength parameters and associated stability problems.

Clays compacted below optimum moisture may swell excessively. Smaller lake plains may be difficult to recognize because recent erosion may have significantly altered the originally flat topography. Granular beach ridges are commonly associated with the large glacial lakes and these beaches are frequently excellent sources of sand and gravel.

C. WIND-BLOWN DEPOSITS

1. Loess - Silt size sediments blown about and redeposited by wind. Grains are angular and of about the same size (uniformly graded.) Cuts may stand vertically for some time; however, if left exposed they are susceptible to wind and water erosion. Silty soils are frost susceptible. Loess occurs predominantly in southeastern Minnesota and in a smaller area of extreme southwestern Minnesota.
2. Dune Sand - Fine sand blown about and deposited by the wind. Exhibits a rather uniform grain size and individual grains have a dull or frosted appearance. As with most clean sands, stability under equipment may pose construction problem. Such formations are found in areas of Norman, Polk, Anoka, Chisago, Isanti, and Sherburne Counties and to a lesser degree in Mille Lacs, Ramsey and Hennepin Counties.

D. RECENT SEDIMENTS

Modern or recent sediments are those soils deposited or formed since the last glacial period. These would include such features as flood plain sediments (alluvial), modern lake clays and beaches (lacustrine), and marl.

1. Alluvial - Soils which have been deposited along a stream or river forming flood plains, terraces, bars, deltas and levees. The kind of material deposited normally depends in part upon the rate of water flow. When the current is rapid, heavier granular particles such as sand or gravel settle out forming granular bars or terraces. Finer grained silt and clay eventually are deposited when the water becomes less turbulent, often forming deltas and levees.
2. Lacustrine - Fine-grained sediments deposited in fresh water lakes which may or may not still be in existence. Wave action in lakes carry the finer grained silt and clay sized particles in suspension towards deeper water. As the water calms, these particles settle out and accumulate in the lake bed to form what is known as lacustrine soil. (As mentioned earlier, many lacustrine sediments in Minnesota were formed in glacial lakes.) Old lake plains are frequently evidenced by a very flat topography.
3. Peat Deposits - Peat is the accumulation of organic debris in various stages of decay. Peat is considered to be a unsuitable material for road construction and is normally mixed with variable amounts of mineral soils. Peat normally accumulates in shallow water areas where drainage is poor.

4. Marl - Soil which is a white to light gray mixture of the mineral calcium carbonate and silt to clay. It forms in the bottom of lakes and swamps, mostly from calcium carbonate precipitating out of ground water, but sometimes from accumulations of shell fragments or chemical action of aquatic plants. Marl will bubble when treated with dilute hydrochloric acid and care should be taken not to confuse it with the fine, light gray sands sometimes found in the bottom of swamps. Marl is also an unsuitable material for roadway construction.

E. GRAVITY DEPOSITS

These deposits are technically referred to as colluvium and would include such features as landslides, surface mud slides, talus etc. Although not particularly common in Minnesota and usually of rather limited extent, this type of deposit frequently indicates an unstable area or one susceptible to rock fall. These problem zones can usually be visually identified in the field, as they lie at the base of a hill or rock outcrop. Highly variable soil conditions can be expected.

F. RESIDUAL SOILS

Residual deposits are those soils that develop inplace on top of the underlying bedrock from hundreds to thousands of years of weathering. In most areas, any residual soils developed on the rock surface were eroded during glacial time, but south of St. Cloud and in the Central part of the State, a variable mantle of white to gray to greenish clay and gritty quartz residue has developed and been preserved on top of the underlying igneous and metamorphic bedrock. (This clay may look a little like marl, but it will not bubble if treated with acid.) Also, a small part of Southeastern Minnesota is believed to be essentially non-glaciated (drift-less area) and here a mantle of dark orange to brown to rusty colored clays been developed on top of the sedimentary dolostone bedrock. Engineering treatment of these clays would be similar to their glacial counterparts. In areas underlain by carbonate bedrock, sinkholes may form where the surface soils erode into solution cavities in the limestone or dolostone. Every effort must be made to seal the access to the cavity to prevent future roadway settlement.

In summary, geological deposits influence the character of the soils developed upon them. The history of geological formations is important to the transportation engineer in that it adds to his understanding of soil characteristics, values, and uses. Glacial drift deposits are usually the most complicated and troublesome to deal with in road construction. Because of the seemingly random nature of their deposition by the glaciers, soils can be quite non-uniform and unpredictable. Unweathered parent, or "C" horizon material for instance, may have many abrupt changes in soil texture such as pocketed gravel, sand and silt-clay materials. Such sharp variations are the most common cause for differential or non-uniform frost heaving. On the other hand, glacial drift furnishes a large percentage of the aggregates needed for construction. Loessial silts and lacustrine clays are also troublesome materials to work with on road construction due to their affinity for capillary water and swell characteristics and their potential for frost heaving and thaw weakening.

Additional information on Minnesota's geology is available in the Geotechnical and Pavement Manual.

Summary of ice activity during the Wisconsin glaciation reconstructed from the distribution of glacial sediments and landforms (after Ojakangas and Matsch, 1982).

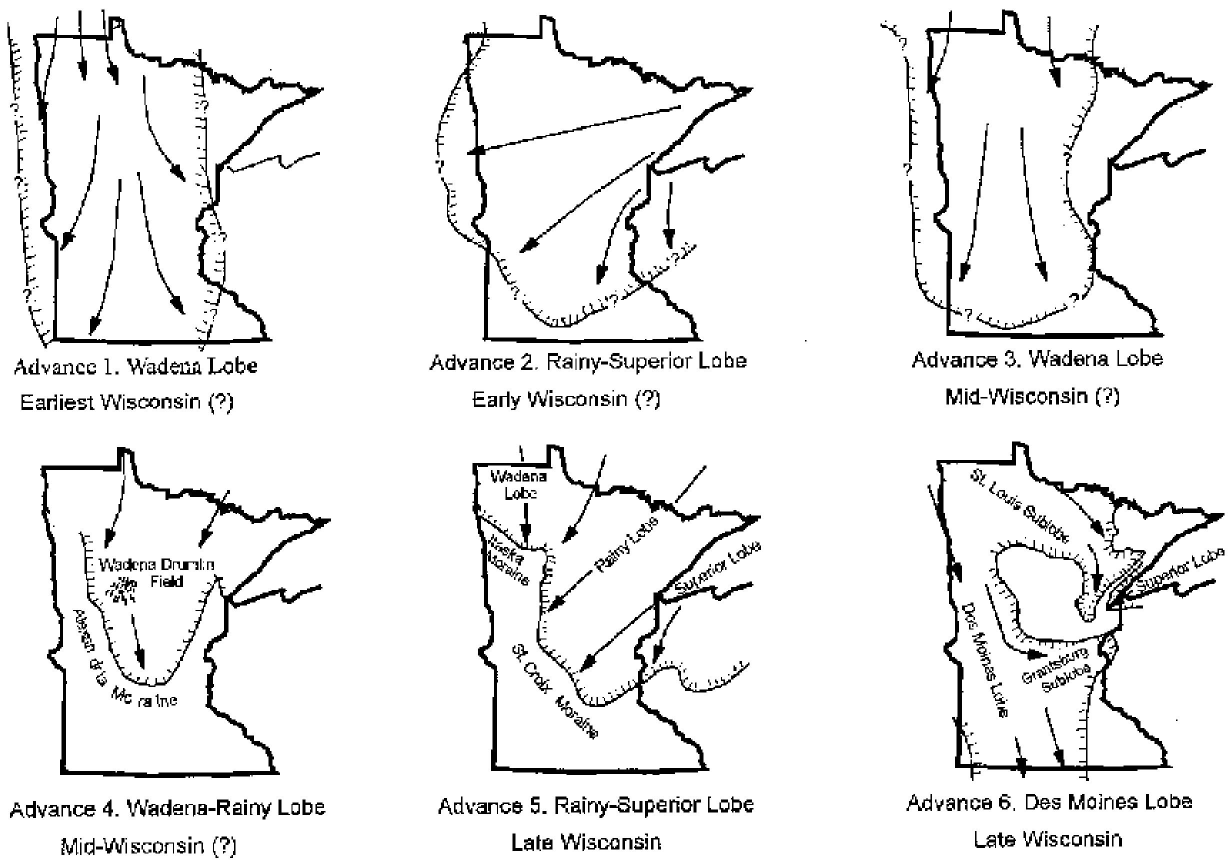


Figure 1 5-692.625

5-692.630 SOIL SELECTION

Soils selection provides the means for utilizing the knowledge of soils and the principles discussed in the preceding sections. In making preliminary soil surveys for design, the principal objective is to discover what soil materials and moisture conditions may be encountered along the proposed grade line. Representative samples are selected and tested in the laboratory to evaluate the soils on the basis of their engineering properties. That information is then applied to the project design to provide for a stable and uniform grade.

Stated simply, the purpose behind the application of the soils data to the design of a grading project is to make use of the better soils where they will do the most good, dispose of the poorer soils where they will have the least detrimental effect upon the finished road and to blend non-uniform soils into a more uniform mass.

The effectiveness and success of that principle depends to a large extent upon the knowledge and diligence of the inspector in seeing that the intent of the plans is carried out. To accomplish this he must have and understand the project soils profile. The soils profile will show the original ground line to which the soils borings will be referenced and the grading profile line to which the project will be built. Normally soils will be removed (subcut) under all portions of the roadway under construction so the structure will have a good foundation. The reasons for removals are as follows:

Topsoil Removal:
To remove organic materials which are moisture susceptible and compressible.

Compaction Subcut:
Inplace materials are acceptable for strength but may not have uniformity or adequate density. Soils removed can be used on the project.

Subgrade Correction or Excavation:
The inplace soils are not acceptable because of a deficiency in engineering properties or because the soils are non-uniform. Two methods of correction are possible, one is to remove the unsuitable soils and replace them with suitable materials and second is to upgrade the inplace soils by blending for more uniformity, reducing or increasing moisture contents to desired levels. Granular materials are used to replace unsuitable soils in a non-granular soil grade when in addition to unsuitable soils subgrade moisture problems also exist.

In design a uniform subcut depth should be maintained wherever possible. When subcut depths have to be varied, 20 to 1 tapers should be provided at both ends. These tapers will allow for relatively smooth transitions.

Soil borings are normally taken on 30 meter (100 feet) intervals and may be taken many years in advance of construction. Therefore, soil conditions and water levels found during construction may differ substantially over short areas from those shown on the profile.

For example, in grading through a cut section, it is entirely possible that pockets of detrimental silty material may be encountered not shown on the soils profile. These pockets should be removed during construction and the excavations filled with more suitable material. Poor soil placed in the upper portion of the embankment may cause premature failure.

The grading inspector's duty is to insure the actual construction meets the intent of the plan and specifications. Therefore, if marked differences do occur, materials or construction limits can and should be altered.

5-692.800
FORMULAS AND COMPUTATIONS

5-692.802 COMPUTATION OF STABILIZED GRAVEL MIXTURE

COMPUTATION OF STABILIZED GRAVEL MIXTURE TABLE A							
Percent Passing Sieve	**25 mm**	**19 mm**	**9.5 mm**	**4.75 mm**	**2 mm**	**425 Φm**	**75 Φm**
Original Gravel	85	80	75	60	50	20	2
Screened Gravel (Oversized Removed)	100	94	88	71	59	24	2.4
Oversize Gravel Crushed	100	90	70	30	10	2	-----
Recombining:							
85% Screened Gravel	85	80	75	60	50	20	2
15% Crushed Oversize	15	13	11	5	2	----	----
Recombined Gravel	100	93	86	65	52	20	2
Binder Soil	100	100	100	100	100	80	50
Computation of Mixture:							
90% Gravel	90	84	77	59	47	18	1.8
10% Binder Soil	10	10	10	10	10	8	5.0
Mixture	100	94	87	69	57	26	6.8
Allowable Spec. Range	100	90-100	50-90	35-80	20-65	10-35	3-10

5-693.803M COMPUTATION OF QUANTITIES FOR BASE CONSTRUCTION (METRIC)

The total quantities of dry base required per kilometer of roadway may be calculated by multiplying the cubic meters (m^3) of compacted dry material required by the dry density (kg/m^3) of the compacted base.

Example:
  Depth of base = 150 mm
  Average width of base = 10 m
  Dry density of compact base = 2160 kg/m^3

One sq. meter (m^2) of base 25 mm thick requires:
  1 m x 1 m x .025 m x 2160 = 54 kg /m^2 / 25 mm

Area per kilometer by 10 meters wide = 1000 m x 10 m = 10000 m^2

One kilometer of base 150 mm thick requires:

$$\frac{10000 \text{ x } 54}{1000} \text{ x } \frac{150}{25} = 3240 \text{ metric ton (t)}$$

To correct for moisture contained in the base multiply the weight of base by percent moisture and add it to the weight of dry material required.

Example:

% moisture of dry weight - 3.5%

$$\text{Wt. of moist aggregate} = 3240 + \frac{(3240 \ x \ 3.5)}{100} = 3353 \text{ t}$$

5-693.803E COMPUTATION OF QUANTITIES FOR BASE CONSTRUCTION (ENGLISH)

The total quantities of dry base required per mile of roadway may be calculated by multiplying the cubic yards of compacted dry material required by the dry density (lb. per $ft.^3$) of the compacted base.

Example:

Depth of base = 6 in.
Average width of base = 30 ft.
Dry density of compact base = 140 lb. per $ft.^3$

One sq. yd. of base one inch thick requires:
3 x 3 x 1/12 x 140 = 105 lb. per $yd.^2$ per inch

$$\text{Area per mile 30 ft. wide} = \frac{5280 \ x \ 30}{9} = 17{,}600 \text{ yd.}^2$$

One mile of base 6 inches thick requires:

$$\frac{17{,}600 \text{ x } 105 \text{ x } 6}{2000} = 5{,}544 \text{ tons}$$

To correct for moisture contained in the base multiple the weight of base by percent moisture and add it to the weight of dry material required.

Example:

% moisture of dry weight - 3.5%

$$\text{Wt. of moist aggregate} = 5{,}544 + \frac{(5{,}544 \text{ x } 3.5)}{100} = 5{,}738 \text{ tons}$$

5-692.804M EXAMPLE CALCULATIONS FOR DETERMINING QUANTITIES OF INGREDIENTS PER KILOMETER OF BASE CONSTRUCTION (METRIC)

Given:
Proportion %: 90% gravel and 10% binder soil.

Assume 3240 metric ton of dry base aggregate is used per kilometer of base construction.

Assume moisture content:

Gravel - 3.5%
Binder Soil - 5.0%

Assume the dry density of the gravel is 1680 kg [1.68 metric ton (t)] per cubic meter and the dry density of the binder soil is 862 kg [0.86 metric ton per cubic meter (m^3)].

Then:

1. Weight of dry gravel in 1 km of base construction is
   3240 x 0.9 = 2916 metric ton (t).
   Weight of dry binder soil in 1 km of base construction is
   3240 x 0.1 = 324 metric ton (t).

2. Volume of gravel in 1 km of base is:

   $$\frac{2916 \text{ metric ton}}{1736 \text{ cubic meters}} = 1.68 \text{ metric ton / cubic meter}$$

   Volume of binder soil in 1 km of base is:

   $$\frac{324 \text{ metric ton}}{377 \text{ cubic meters}} = 0.86 \text{ metric ton / cubic meter}$$

3. Weight of moist gravel taken from pit is:

   2916 x 1.035 = 3018 metric ton (t)

   Weight of moist binder soil taken from pit is:

   324 x 1.05 = 340 metric ton (t)

4. Water for compaction.
   Assume: mixture contains 4% water. Optimum moisture content for mixture is 8%.
   Required additional moisture is 4%.
   One metric ton (t) of dry mixture requires:

   0.04 x 1000 kg = 40 kg

   Since 1 kg = 1000 g and 1 g = 1 ml

Therefore:

1 kg = 1000 m1 or 1 liter (1)

$$\frac{40}{1} = 40 \text{ liter (l)}$$

One kilometer (km) requires: 40 liters x 3240 = 129600 liters (l) or 129.6 kl.

The designed gradation of the stabilized mixture is based upon the average gradation of gravel and binder soil which are expected to be produced from the designated sources. If, when production of material for construction has been started, it is found that the actual gradation of gravel varies from that assumed in design, some adjustment of proportions may be necessary.

In making field adjustments of proportions, the following formula may be helpful:

$$A = 100 \ \frac{(P - C)}{(B - C)}$$

Where:

A = percent of binder soil in mix.
B = percent of binder soil which passes certain sieve size.
C = percent of gravel which passes certain sieve size.
P = desired percent of stabilized mixture passing certain sieve size.

Examples:

1. If, in the previous example of design of a stabilized mixture, it is desired to maintain 26% passing the 425 µm sieve and the gravel has 22% passing the 425 µm, the formula could be applied as follows:

$$A = 100 \ \frac{(26 - 22)}{(80 - 22)} = \frac{400}{58} = 6.9\%$$

Therefore:
Only 6.9% of binder soil would have to be added.

2. This formula, expressed in a different form, may also be used to determine what variation in gradation of gravel on a certain sieve size is allowable if the percentage of binder soil remains constant. For this purpose the formula is expressed as follows:

$$C = \frac{100\ P - AB}{100 - A}$$

If the specifications require from 5% to 10% passing the 75 µm sieve for the stabilized mixture and 10% of binder soil containing 50% passing the 75 µm sieve were specified, then the maximum allowable percentage of gravel passing a 75 µm sieve could be determined as follows:

$$C = \frac{(100 \times 10) - (10 \times 50)}{100 - 10} = \frac{500}{.90} = 5.5$$

Therefore:
5.5% passing the 75 µm sieve is the maximum allowable for the gravel material.

5-692.804E EXAMPLE CALCULATIONS FOR DETERMINING QUANTITIES OF INGREDIENTS PER MILE OF BASE CONSTRUCTION (ENGLISH)

Assume 90% gravel and 10% binder soil.

1. Gravel

   5,544 x 0.9 = 4,990 tons of dry gravel

   Average moisture content of gravel from pits is approximately 3.5%.

   Weight of moist gravel as taken from pit = 4,900 x 1.035 = 5,164 tons.

   One cubic yard (yd^3) of moist gravel loaded in truck may be assumed to contain 2,800 lbs. or 1.4 ton of dry gravel.

   Volume of gravel = $\frac{4{,}990}{1.4} = 3{,}564 \text{ yds.}^3$

2. Binder soil

   5,544 x 0.10 = 554.4 tons of dry binder. To convert to cubic yards for volumetric measurement:

   Average binder soil loaded in truck may be assumed to contain 1,900 lb. or 0.95 tons of dry material in one cubic yard.

   $$\frac{554.4}{0.95} = 584 \text{ yd.}^3$$

3. Water for compaction.

   Assume: Mixture contains 4% water. Optimum moisture content for mixture is 8%.

   Required additional moisture is 4%.

   One ton of dry mixture requires:

   0.04 x 2,000 = 80 lb. water

   $$\frac{80}{8.3} = 9.6 \text{ gallons}$$

   One mile requires:

9.6 x 5,544 = 53,222 gallons

The designed gradation of the stabilized mixture is based upon the average gradation of gravel and binder soil which are expected to be produced from the designated sources. If, when production of material for construction has been started, it is found that the actual gradation of gravel varies from that assumed in design, some adjustment of proportions may be necessary.

In making field adjustments of proportions, the following formula may be helpful:

$$A = 100 \frac{(P - C)}{(B - C)}$$

Where:
A = percent of binder soil in mix.
B = percent of binder soil which passes certain sieve size.
C = percent of gravel which passes certain sieve size.
P = desired percent of stabilized mixture passing certain sieve size.

Examples:

1. If, in the previous example of design of a stabilized mixture, it is desired to maintain 26% passing the No. 40 sieve and the gravel has 22% passing the No. 40, the formula could be applied as follows:

$$A = 100 \frac{(26 - 22)}{(80 - 22)} = \frac{400}{58} = 6.9\%$$

Therefore:
Only 6.9% of binder soil would have to be added.

2. This formula, expressed in a different form, may also be used to determine what variation in gradation of gravel on a certain sieve size is allowable if the percentage of binder soil remains constant. For this purpose the formula is expressed as follows:

$$C = \frac{100\ P - AB}{100 - A}$$

If the specifications require from 5% to 10% passing the No. 200 sieve for the stabilized mixture and 10% of binder soil containing 50% passing the No. 200 sieve were specified, then the maximum allowable percentage of gravel passing a No. 200 sieve could be determined as follows:

$$C = \frac{(100 \times 10) - (10 \times 50)}{100 - 10} = \frac{500}{.90} = 5.5$$

Therefore:
5.5% passing the No. 200 sieve is the maximum allowable for the gravel material.

5-692.805 PROCEDURE FOR "ROUNDING OFF"

A. To "round off" a numerical value is to reduce the number of recorded figures to some predetermined point by dropping figures or by increasing the value of certain figures. For example, a computed, observed, or accumulated value such as 4,738,221 can be rounded off to the nearest million (5,000,000); to the nearest hundred thousand (4,700,000); to the nearest ten thousand (4,740,000); etc. Similarly, a value such as 47.382 can be rounded off to two decimal places (47.38); to one decimal place (47.4); to the nearest whole number or units place (47); etc.

B. The general rule for rounding off are as follows:

1. When the figure next beyond the last figure or place to be retained is less than 5, the figure in the last place retained is unchanged. (4,738,221 rounded off to the nearest hundred thousand is 4,700,000 and 47.382 rounded to two decimal places is 47.38)
2. When the figure next beyond the last figure or place to be retained is greater than 5, the figure in the last place retained is increased by 1 (4,738,221 rounded to the nearest million is 5,000,000 and 47.382 rounded to one decimal place is 47.4)
3. When the figure next beyond the last figure to be retained is 5 followed by any figures other than zero(s), the figure in the last place retained is increased by 1 (4,500,001 rounded to the nearest million is 5,000,000 and 4.6501 rounded to one decimal place is 4.7

4. When the figure next beyond the last figure to be retained is 5 followed by only zeros, the figure in the last place to be retained is left unchanged if it is even (0,2,4,6 or 8) or is increased by 1 if it is odd (1,3,5,7 or 9). When rounded to the nearest million 4,500,000 is 4,000,000; 5,500,000 is 6,000,000. When rounded to one decimal point 4.25 is 4.2; 4.15 is 4.2; 47.05 is 47.0 and 47.95 is 48.0.
5. Any number required to be rounded off shall be rounded off in one step, not by a series of rounding operations. <u>For example, 47.3499 rounded to one decimal place is 47.3 not 47.4</u>, which is the result if 47.3499 is rounded to 2 decimal places (47.35) and then rounded to 1 decimal place (47.4).

C. Application of Rounding Off Rules

1. Reading indications on graduated scales such as found on balances, gauges and dials.
   a. When the indicator is between two graduations, read the value of the closest graduation.
   b. When the indicator is midway between graduations, read the value of the “even” graduation, (if the indicator is midway between 9.8 and 9.9 read 9.8; if the indicator is midway between 9.9 and 10.0 read 10.0).
   c. A special case exists when the graduations of all have even values. When the indicator is midway between 2 “even” graduations, read the intermediate or “odd” value (if the pointer on a Speedy moisture dial is midway between 10.6 and 10.8, read 10.7).

2. Rounding off to the nearest 50, 5, 0.5, 0.05, etc.

   To round a number to the nearest 50, 5, 0.5, 0.05, etc. double the observed or calculated value, round the product to the nearest 100, 10, 1.0, 0.10, etc. in accordance with the rules in part B above and divide the rounded product by 2. (6025 rounded to the nearest 50 is 12,050 rounded to the nearest 1000 which is 12,000 and 12,000 divided by 2 is 6,000.)

3. Rounding common fractions

   When rounding common fractions, the rules are applied to the numerators of the fractions which are reduced to a common denominator. The observed fraction is compared to the fraction “rounded to” and the remainder is dropped if it is less than ½ of the fraction “rounded to” and increased if it is more than ½ of the fraction “rounded to”; if the remainder is exactly ½ of the fraction “rounded to” the odd-even rules are used. Consider the following examples:

When rounded to the nearest eighth (4/32):

1-1/32 becomes 1 because 1/32 is less than ½ of 4/32 and is dropped.

1-2/32 becomes 1 because 2/32 is exactly ½ of 4/32, the 2/32 is dropped because the numerator of the preceding eighth (0/8) is even.

1-3/32 becomes 1-4/32 or 1-1/8 because 3/32 is more than ½ of 4/32, therefore the fraction is increased or "rounded up" to the next eighth.

1-5/32 becomes 1-4/32 or 1-1/8 because 5/32 is 1/32 more than 4/32, 1/32 is less than ½ of 4/32 and therefore is dropped.

1-6/32 becomes 1-2/8 or 1-1/4 because 6/32 is 2/32 more than 4/32 and the numerator of the preceding eighth (1/8) is odd, therefore the fraction is increased to the next eighth.

1-7/32 becomes 1-2/8 or 1-1/4 because 7/32 is 3/32 more than 4/32 or an exact 1/8 and 3/32 is more than ½ of 4/32, therefore the fraction is increased to 2/8 or "rounded up".

1-10/32 becomes 1-2/8 or 1-1/4 because 10/32 is 2/32 more than 8/32 or an exact 2/8, 2/32 is ½ of 4/32, the numerator of the preceding eighth (2/8) is even, therefore the 2/32 is dropped or "rounded down".

5-692.806 METRIC & ENGLISH EQUIVALENT GRADATION SIEVE SIZES

METRIC		ENGLISH	
75.0 mm	-	(3”)	Sieve
50.0 mm	-	(2”)	Sieve
37.5 mm	-	(1 1/2”)	Sieve
31.5 mm	-	(1 1/4”)	Sieve
25.0 mm	-	(1”)	Sieve
19.0 mm	-	(3/4”)	Sieve
16.0 mm	-	(5/8”)	Sieve
12.5 mm	-	(1/2”)	Sieve
9.5 mm	-	(3/8”)	Sieve
4.75 mm	-	(#4)	Sieve
2.38 mm	-	(#8)	Sieve
2.00 mm	-	(#10)	Sieve
1.19 mm	-	(#16)	Sieve
850 µm	-	(#20)	Sieve
600 µm	-	(#30)	Sieve
425 µm	-	(#40)	Sieve
300 µm	-	(#50)	Sieve
180 µm	-	(#80)	Sieve
150 µm	-	(#100)	Sieve
75 µm	-	(#200)	Sieve